This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

POETICAL WORKS OF THOMAS MOORE.

[illegible]

[illegible]

ELEMENTS OF MECHANISM

LONDON
PRINTED BY SPOTTISWOODE AND CO.
NEW-STREET SQUARE

THE

ELEMENTS OF MECHANISM

DESIGNED FOR STUDENTS OF APPLIED MECHANICS

BY

T. M. GOODEVE, M.A.

PROFESSOR OF NATURAL PHILOSOPHY IN KING'S COLLEGE, LONDON

LONDON
LONGMAN, GREEN, LONGMAN, AND ROBERTS
1860

186. b. 10.

BODLEIANA · BIBLIOTHECA

PREFACE.

THE present Treatise has been written with the view of providing an Elementary Text-book upon the Principles of Mechanism for the Students in the Applied Science Department of King's College.

The method of classification which has been adopted may perhaps fail to satisfy a very critical reader, and is no doubt open to objection. The Author would, however, remark that this book is simply designed to serve as an introduction to the elaborate and highly philosophical work of Professor Willis, and is not intended to stand alone as sufficient in itself.

KING'S COLLEGE, LONDON: June 1860.

TABLE OF CONTENTS.

INTRODUCTION.

General Statement. Definitions. Spur, Crown, and Bevil Wheels. Screw Surface. Screw Thread. Pitch of a Screw. Worm Wheel. Belts or Bands. Shafting. Arbor. Driver. Follower. Gearing or Gear - - - - - - - Page 1

CHAPTER I.

ON THE CONVERSION OF CIRCULAR INTO RECIPROCATING MOTION.

Art. 1—3. Elementary Considerations. 4. The Crank and Connecting Rod. 5. The Eccentric Circle. 6. The Swash Plate. 7. The Eccentric. 8—10. Intermittent Motion. 11—14. Escapements. 15—29. Cams of various kinds: the Heart Wheel, the Worm Barrel, the Expansion Cam, Double Cams. 30—35. Mangle Wheels and Racks. 36—43. Circular in Reciprocating Motion by Wheelwork: Collier's Planing Machine, Whitworth's Reversing Motions, Screwing Machines. 44, 45. Crossed and Open Bands. 46—50. Reciprocating Motion with a Quick Return: Whitworth's Shaping Machine. 51. Stanhope Levers. 52, 53. Reciprocation by Linkwork - 8

CHAP. II.

ON THE CONVERSION OF RECIPROCATING INTO CIRCULAR MOTION.

Art. 54—56. General Principles. 57. Ratchet Wheels. 58. Practical Subdivision of the Teeth. 59. Detent. 60. Equivalent for a Ratchet Wheel. 61, 62. Feed in a Planing Machine. 63. Escapement. 64. Levers of Lagarousse. 65. Screw Barrel - 45

CHAP. III.

ON THE TEETH OF WHEELS.

Art. 66—68. Statement of the Problem. 69. Epicycloid and Hypocycloid. 70—72. Solution of the Problem. 73—75. Teeth with Radial Flanks. 76—78. Pin Wheels. 79, 80. Involute Teeth. 81, 82. Racks and Pinions. 83—87. General Considerations. 88. Bevil Wheels - - - - - - - 53

CHAP. IV.

ON THE USE OF WHEELS IN TRAINS.

Art. 89—91. Wheels in Trains: Value of the Train, Idle Wheels, Marlborough Wheel. 92. Circular and Diametral Pitch. 93. Eight-day Clock. 94. The Screw-cutting Lathe. 95. Reducing Motion. 96, 97. Connection of Axes - - - - Page 70

CHAP. V.

ON AGGREGATE MOTION.

Art. 98—100. Examples: Lazy Tongs, Differential Screw, Chinese Windlass. 101, 102. Epicyclic Trains. 103. Ferguson's Paradox. 104. Sun and Planet Wheels. 105—107. Houldsworth's Bobbin Motion. 108. Phases of the Moon. 109. Slow Motion. 110. Comparison of Fixed and Epicyclic Trains. 111. Equation Clocks. 112—116. Parallel Motion. 117. Deviation from the Vertical. 118. Similar Curves. 119. The Pantograph. 120, 121. Parallel Motions of Beam Engines. 122, 123. Parallel Motion of the "Gorgon" Engines. 124. Parallel Motion for rolling Steel Plates. 125—128. Drilling and Boring Machinery. 130. Wheel Rolling. 131. Watt's Indicator. 132, 133. The oval Chuck. 134. Siemen's Chronometric Governor - - - - - - 83

CHAP. VI.

ON MISCELLANEOUS CONTRIVANCES.

Art. 135—142. The Fusee and its Applications : Formation of a "Cop," Roberts's Winding-on Motion, Screw of varying Pitch, The Snail, The Disc and Roller. 143. Conical Pulleys. 144. Speed Pulleys. 145—147. Rolling Curves. 148. The Double Eccentric 149. Bell Crank Levers. 150. The Geneva Stop. 151. The Star Wheel. 152. Counting Wheels ; The Differential Worm Wheel. 153. The Toggle Joint. 154. Saxton's Differential Pulleys. 155. Step Wheels. 156. Hooke's Joint - - - - - - - 121

ELEMENTS OF MECHANISM.

INTRODUCTION.

A MACHINE may be defined to be an assemblage of moving parts, constructed for the purpose of transmitting motion or force, and of modifying, in various ways, the motion or force so transmitted.

The parts of a machine are set in motion by some moving power, which may be derived from any convenient source, and the machine itself must be constructed with reference to the character of the power from which its motion is derived.

The introduction of the steam-engine has greatly simplified the art of constructive mechanism, by rendering the source of power uniform and undeviating; the steam-engine is always employed to give rotation to a piece of shafting, and the mechanic is required to derive from the smooth and steady rotation of a shaft every movement which the nature of the work may demand. Thus the starting point for steam-machinery is everywhere the same, and the problem of making a machine resolves itself into a question of the resolution or transfer of circular motion in every variety of manner, and subject to every possible modification.

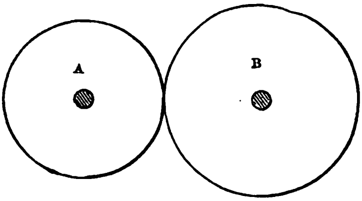
Accordingly we propose to commence with a discussion of the methods adopted for the conversion of circular into reciprocating motion; then to proceed to the inverse problem, or to examine the conversion of reciprocating into circular motion; to pass on to an enquiry into the results deduced from combinations of wheelwork in trains, giving the theory which has led to an accurate shaping of the teeth of wheels; to consider, further, some arrangements by which a moving piece may be made the recipient of two or more independent motions; and finally, to conclude by collecting and analysing certain miscellaneous contrivances which produce results of a specific and very noticeable character.

It will be necessary to premise a few general remarks and definitions.

In the transfer of motion or force from one axis to another, wheels furnished with teeth are commonly employed. The various calculations connected with the forms of teeth which are suitable for this purpose will be given hereafter; at the present time we may remark, that the most simple case of the transfer of motion from one axis to another occurs when a circular disc or plate moves another by rolling contact.

In such a case the uniform motion of the axis, A, conveys a perfectly even and uniform motion to the other axis, B. (Fig. 1.)

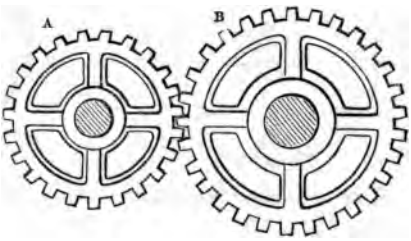
Fig. 1.



If A and B were circular plates with smooth flat edges, and very accurately adjusted, we might expect A to move B by friction alone, without any slipping of the surfaces in contact, but we could never expect A to overcome any great resistance to motion in B; or, in other words, we could not convey force by the action of one disc upon the other.

The transmission of force being an essential condition in machinery, the discs A and B are provided with teeth as in the annexed figure, and the mechanist endeavours so to form and shape the teeth that the motion shall be exactly the same as if one circle rolled upon another.

Fig. 2.



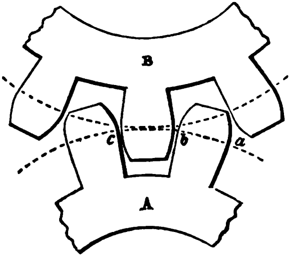
Herein consists the perfection of wheel-work, a perfectly uniform motion of the axis A is to be conveyed by means of teeth to the axis B; and the motion of B, when tested with microscopic accuracy, is to be no less even and uniform than that of A.

Since, then, it appears that the motions of A and B are exactly the same as those of two circles rolling upon each other, such imaginary circles may always be conceived to exist, and are called the *pitch circles* of the wheels in question. They are represented by the dotted lines in the annexed sketch.

So much of the tooth as lies within the pitch circle is called its *root* or *flank*, and the portion beyond the pitch circle is called the *point* or *addendum*.

The *pitch of a tooth* is the space *a c* upon the pitch circle cut off by the corresponding edges of two consecutive teeth. (Fig 3.)

Fig. 3.



Spur wheels are represented in Fig. 2, and are those in which the teeth stand out radially along the circumference.

In a *face wheel* the cogs or pins are placed perpendicularly to the plane of the wheel. (Fig. 4.)

Fig. 4.

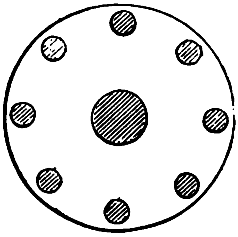
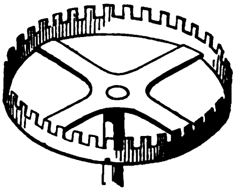


Fig. 5.



A *crown wheel* is provided with teeth upon the edge of its rim (Fig. 5.)

In *annular wheels* the teeth are cut upon the inside of an annulus or ring.

A straight bar, provided with teeth, is called a *rack*, and a wheel with a small number of teeth is termed a *pinion*.

The wheels A and B are suited to convey motion only between parallel axes; it often happens, however, that the axes concerned in any movement are not parallel, and as a consequence they may, or may not, meet in a point. In the latter case we proceed by successive steps and continually introduce intermediate intersecting axes, and thus we are led to the use of inclined wheels whose axes meet each other, and which are known as *Bevil wheels*. (Fig. 6.) It is a well known fact in Geometry that two right cones which have a common vertex will roll upon each other, and the same would be true of the frustra of two cones as C R P B, D Q P B, in Fig. 7. The rolling of the cones will allow us

Fig. 6.

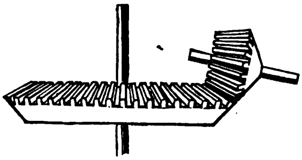
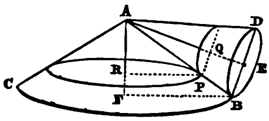


Fig. 7.



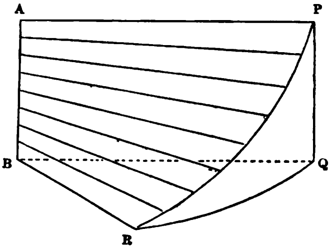
to consider any pair of circles in contact as the pitch circles of the cones, and teeth may be shaped upon the frustra, so as to produce the same even motion as that which exists in the case of spur wheels.

Equal bevil wheels whose axes are at right angles are termed *mitre wheels.*

It is sometimes convenient that the axes of the bevil wheels should pass close to each other without intersecting; the teeth have then a peculiar form, and the wheels are known as *skew bevils.*

If a horizontal line A P, Fig. 8, revolve uniformly in one direction, and at the same time be made to ascend or descend with a uniform velocity, it will trace out a *screw surface* A P R B. The points of intersection of this generating line with any circular cylinder whose axis coincides with A B, will form a screw thread, P R, upon the surface of such cylinder.

Fig. 8.



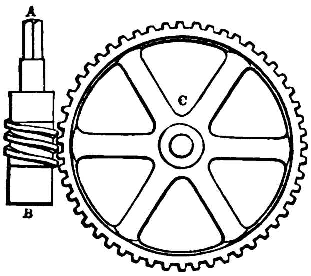
The *screw thread* used in machinery is a projecting rim of a certain definite form, running round the cylinder and obeying the same geometrical law as the ideal thread just described.

The *pitch of a screw* is the space along A B, through which the generating line moves in completing one entire revolution, but in practice the pitch of a screw bolt is usually estimated by observing the number of ridges which occur in an inch of its length; thus we speak of the screw of one-eighth of an inch pitch as being a screw with eight threads to the inch.

Also A B is called the *length* of the screw surface A P R B, and the angle P R Q is called the angle of the screw. In Fig. 8, A P is describing a right-handed screw during its descent; if it revolved in the opposite direction and descended it would describe a left-handed screw.

A *worm wheel* is a wheel furnished with teeth set obliquely upon its rim, and so shaped as to be capable of engaging with the thread of a screw. The revolutions of the *endless screw* or *worm*, A B, (Fig. 9.), will thus impart rotation to the wheel C, and the wheel will advance through the space of one tooth upon each revolution of the screw.

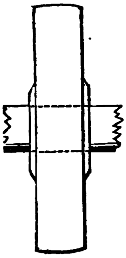
Fig. 9.



If there be two threads upon the screw, the wheel will advance through the space of two teeth for each revolution of A B, and so on.

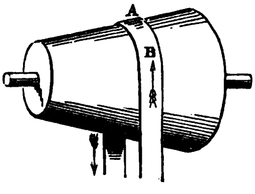
Belts or *bands* are much used in machinery, in order to communicate motion between two axes at a distance from each other. In this case the endless band is stretched over the circumferences of discs or pulleys upon each axis, and the motion is the same as if the discs rolled directly upon each other. The form of each pulley is slightly convex, and the strap will then remain upon the discs.

Fig. 10.



The reason of this curious fact will be apparent if we examine the case of a tight belt running upon a revolving conical pulley. The belt becomes bent into the form A B, shown in Figure 11., the portion B being somewhat nearer to the base of the cone than the portion A.

Fig. 11.



The cone, during its revolution, exerts an effort to carry B onward in a circle parallel to its base, and the consequence is that the belt tends to remain upon the slant surface of the cone, and to rise higher rather than to slip off.

The *fast and loose pulley* is an adjunct of the driving belt. It consists of two pulleys, whereof one is keyed to the shaft to which motion is to be conveyed, and the other rides loose upon it. Motion occurs when the strap is shifted from the loose to the fastened pulley. The band can only be shifted by pressing laterally upon the advancing side.

The advancing portion of a band must always lie in the plane of the pulley round which it is wrapped, but the retreating portion may be pulled on one side without causing the strap to leave the pulley. By observing this principle, a band may be employed to communicate motion between two axes which are not parallel to each other.

The term *axis* denotes the central line of a cylinder, and is a mathematical phrase: an engineer distinguishes a heavy cylindrical piece of metal as *shafting*, or a *shaft*, and designates smaller cylindrical bars as *spindles;* a wheelwright speaks of the *axle* of a wheel, and a watchmaker calls the same thing an *arbor.*

Of two moving pieces, that which transmits motion is termed the *driver*, and that which receives it is the *follower.*

Gearing and *Gear* are the words used to indicate the combination of any number of parts in a machine which are employed for a common object.

Toothed wheels are said to be *in gear* when they are capable of moving each other, and *out of gear* when they are shifted into a position where the teeth cease to act.

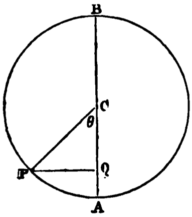
CHAPTER I.

ON THE CONVERSION OF CIRCULAR INTO RECIPROCATING MOTION.

Art. 1. The most simple case of motion is that of a point describing a straight line with a uniform velocity. Whenever a point deviates from a rectilinear path, and describes a plane curve of any form, it must be the subject of two independent movements in lines at right angles to each other.

Thus, let a point, P, (Fig. 12.) describe a circle, A P B, with a uniform velocity, draw P Q $\perp^{r}$ to a diameter, A B; then it is evident that a point describing the arc A P has been the subject of two rectilinear movements, one from A to Q, the other from Q to P. In other words, circular motion is of a compound character, and capable of resolution into its elements; if it be thus resolved, and if one equivalent be suppressed, so that the motion of Q is substituted for that of P, we obtain the fundamental case of the conversion of circular into reciprocating motion.

Fig. 12.



2. Let $CA = a$, $PCA = \theta$; (Fig. 12.)

then $AQ = AC - CQ = a - a\cos\theta = a(1 - \cos\theta)$;

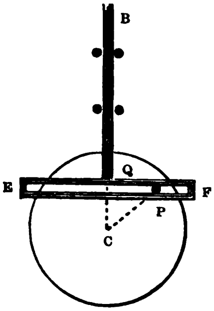
which equation gives the analytical representation of motion of this character.

As the point P moves uniformly round the circumference, the point Q oscillates through the line A B, and its velocity is not uniform, but varies as the sine of θ.

If the motion of Q were compared with that of a point, R, describing A B in the same time with a uniform velocity, it would be found that Q and R coincided in the points A, C, and B; but that R was in advance of Q between A and C, and that Q preceded R from C to B.

3. The motion of Q may be derived from that of P by the following contrivance:—

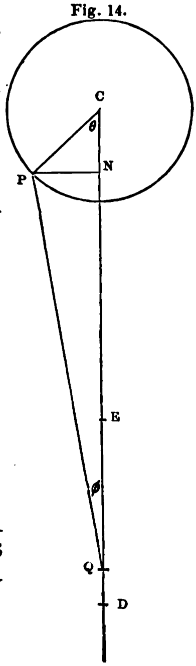
Fig. 13.



Let P (Fig. 13.) represent a small pin set in a circular plate which is moveable about C as a centre of motion, and let the pin work in a groove, E F, whose direction is at right angles to that of the sliding bar, Q B.

Of the two equivalents which combine to produce the circular motion of P, that which occurs in the direction F E is rendered inoperative, and the whole of the other equivalent is imparted to the sliding bar.

Fig. 14.



4. *The Crank and Connecting Rod.*—Let C P be an arm or *crank* centred at C, (Fig. 14.) and connected with the point Q by a link or *connecting rod*, P Q, and suppose, further, that the point Q is constrained to move in the straight line, C E D, we shall find that the revolution of C P will cause Q to reciprocate.

Draw P N $\perp^{r}$ C D, and let C P $= a$,

$$\text{P Q} = b,\ \text{P C Q} = \theta,\ \text{P Q C} = \phi;$$

then $\text{C Q} = \text{C N} + \text{N Q}$

$$= a\cos\theta + b\cos\phi;$$

also $\dfrac{a}{b} = \dfrac{\sin\phi}{\sin\theta}\ \therefore\ \sin\phi = \dfrac{a}{b}\sin\theta$

$$\therefore\ \cos\phi = \sqrt{1 - \frac{a^2\sin^2\theta}{b^2}}$$

$$\therefore\ \text{C Q} = a\cos\theta + \sqrt{b^2 - a^2\sin^2\theta};$$

whence the position of Q is known at any period of the motion of C P.

Cor. 1. Let $\theta = o$ $\therefore$ CD $= a + b$

$\theta = \pi$ $\therefore$ CE $= -a + b$

whence DE (i.e. *the throw of the crank*) = CD − CE = $2a$.

Cor. 2. Again DQ = CD − CQ

$$= a + b - a \cos\theta - b \cos\phi$$
$$= a(1 - \cos\theta) + b(1 - \cos\phi);$$

or the motion of Q differs from that in the last example, by the addition of the movement represented by $b(1 - \cos\phi)$; it is compounded of the resolved parts of two circular motions, the one being that due to the motion of P in a complete circle round C, and the other resulting from the motion of P through a part of a circle whose radius is PQ.

It follows that when DCP is a right angle, Q is not in the middle of its stroke, but that DQ is greater than EQ.

Ex. Let CP = 11 inches } as in a locomotive engine
PQ = 5½ feet } by Stephenson.

Let $\theta = 90$; then $\sin\phi = \frac{\text{CP}}{\text{PQ}} = \frac{11}{66} = \frac{1}{6}$

$$\therefore \cos\phi = \sqrt{1 - \frac{1}{36}} = \sqrt{\frac{35}{36}} = \frac{1}{6}\sqrt{35}.$$

Then DQ $= a(1 - \cos\theta) + b(1 - \cos\phi)$

$$= 11 + 66\left(1 - \frac{1}{6}\sqrt{35}\right)$$
$$= 11 + 11(6 - 5{\cdot}9161)$$
$$= 11 + {\cdot}923 \text{ nearly,}$$

or Q is very nearly an inch in advance of the centre of its path when the crank has made a quarter of a revolution from the line CD.

This inequality in the motion of Q which is caused by the shortness of the connecting rod, produces a sensible effect in the working of direct-acting engines, and makes the mean pressure of the steam greater in the up-stroke, where the piston is gaining in its motion, than in the down-stroke, where the piston is lagging behind.

Cor. 3. If the crank could be prolonged until it became infinite, we should have $\phi = 0$, $\cos\phi = 1$, and the travel of Q represented by the equation $DQ = a\,(1 - \cos\theta)$.

A crank with a connecting rod of infinite length is an imaginary creation, but we can obtain the motion which would result from it in various ways, and we have indeed already met with it in Art. 3.

5. The *Eccentric Circle* supplies a ready method of obtaining a crank and link.

Let P (Fig. 15.) be the centre of a circular plate which is moveable about C as a centre of motion. Q D, a bar capable of sliding in a vertical line through C. As the circle revolves, P Q remains constant, and the motion is that of a crank, C P, with a link, P Q.

Fig. 15.

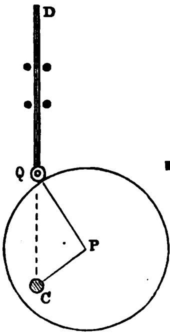


Fig. 16.

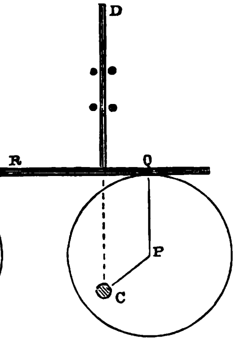
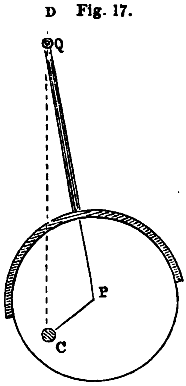


Fig. 17.

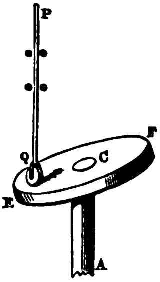


If the roller at Q be replaced by a bar Q R at right angles to D C, (Fig. 16.) we have P Q parallel to itself in all positions, and recur again to the crank with an infinite link.

If the roller at Q be replaced by a portion of a circular hoop which embraces the plate (Fig. 17.) and a point Q in the bar be constrained to move always in the line C D, we shall extend the link beyond the limits of the circular plate, and derive a crank, C P, with an arm, P Q.

6. The crank with an infinite link appears under the guise of the ***swash plate.***

Fig. 18.

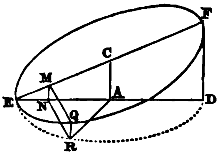


Here a circular plate, E F, (Fig. 18.) is set obliquely upon an axis, A C, and by its rotation drives a sliding bar, P Q, whose direction is parallel to A C.

A small roller at Q relieves the friction between the end of the bar and the plate.

In Fig. 19, E and F represent the highest and lowest points of the path of Q, and the circle E R D is the projection of this path upon a plane $\perp^r$ to the axis A C. Draw Q M $\perp^r$ to E F, Q R $\perp^r$ to the plane E R D, and R N $\perp^r$ to E D; join M N and suppose the axis to rotate through an angle E A R $= \theta$, and thus to carry Q through the vertical space R Q.

Fig. 19.



Then

$$RQ = MN = AC \times \frac{EN}{EA}$$

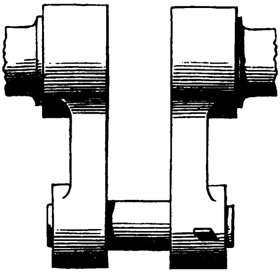
$$= AC\left(\frac{EA - AN}{EA}\right) = AC\left(1 - \frac{AN}{AR}\right)$$

$$= AC\,(1 - \cos\theta);$$

or the motion is that of a crank A C with an infinite link.

7. The crank and connecting rod is a most valuable contrivance, but it labours under the disadvantage of entailing a division of the shaft whenever it is required to place the crank anywhere except at one end. We may see this from the drawing in Fig. 20.

Fig. 20.

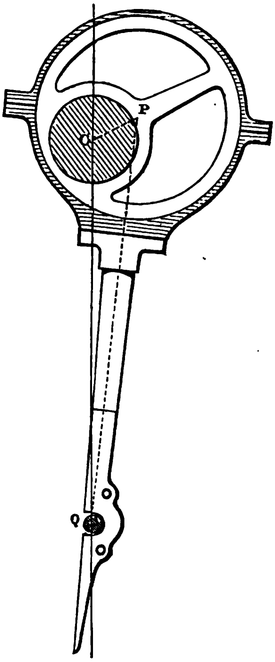


Where a crank of small throw is wanted, as for example in the mechanism for actuating the steam slide valves of an engine, the *crank* may be replaced by an *eccentric.*

Here a circular plate is encircled by a hoop to which a bar is attached : this bar points always to P, the centre of the plate, and its extremity drives a pin Q, which is constrained to move in the line C Q. (Fig. 21.)

The plate is moveable about a centre of motion at C, and we have already explained that P Q remains constant during each revolution of the plate, or that the resulting motion impressed upon Q is that due to a crank, C P, and a link, P Q.

Fig. 21.



We should remark that P, the centre of the plate in question, may be brought as near as we please to C, the centre of the shaft, and that the throw of the crank may be reduced accordingly; but that we are limited in the other direction, for the shaft must be kept within the boundary of the plate, and the plate itself must not be inconveniently large,—considerations which are sufficient to prevent our increasing C P in any great degree.

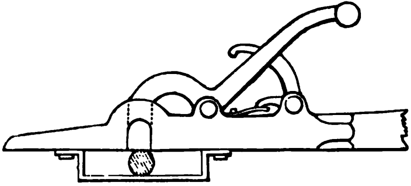
The eccentric circle may also be regarded as a simple form of *cam* (see Art. 15.), but we have examined it here on account of its being identical in principle with the crank and connecting rod.

The object of the complete hoop is to drive Q in alternate directions. In some cases Q is brought back by a spring, and then only half the hoop is required; an instance occurs in modern forging machines, where the motion is very small and rapid.

8. An intermittent motion may be obtained by placing a

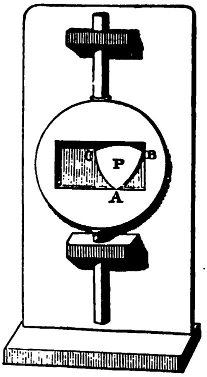
loop at the end of the eccentric bar. If such a loop be provided it can be seen that the pin Q mentioned in Art. 7. can only move when one end of the loop takes it up. If the loop be made long enough and be placed in the right position the pin will not move at all, and we deduce the ordinary method of disengaging an eccentric which is indicated in Fig. 22, where the pin is pushed out of the opening in the bar and remains at rest.

Fig. 22.



9. An intermittent motion may be obtained in a much better manner by a movement adapted for working the valves of a steam-engine.

Fig. 23.



We observe that if any portion of the plate in Art. 5. be shaped in the form of a circle round C, such portion will have no power of moving the sliding bar.

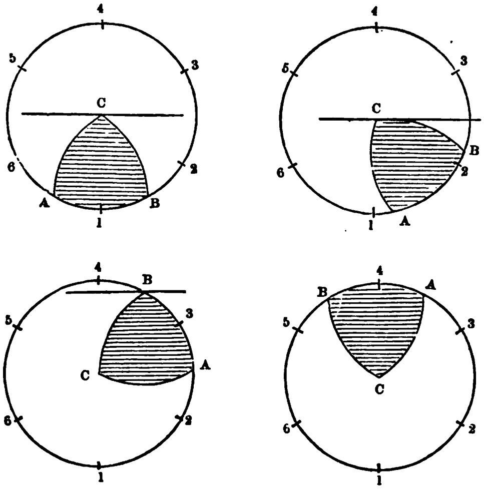
Let the pin P assume the form of a circular equilateral triangle, C A B, centered at C (Fig. 23.), and be embraced by a rectangular frame attached to a sliding rod.

Divide the circle described by B into six equal parts at the points numbered 1, 2, 3, 4, 5, 6. (Fig. 24.)

As B moves from 1 to 2, the frame remains at rest; from 2 to 3 the arc C B drives the frame, and the motion is that of a crank C B with an infinite link; from 3 to 4 the arc B A drives, and the motion is that of a crank C A with an infinite link; *i.e.* the motion from 3 to 4 is the same as that from 2 to 3, except that it is decreasing instead of increasing.

From 4 to 5 there is rest, then an increase of motion from 5 to 6, and finally a decrease to zero as B passes through the arc 6—1 and completes an entire revolution.

Fig. 24.



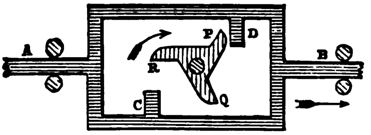
10. We have hitherto confined our attention to one simple example in the geometry of motion: we shall now extend our view of the subject, and shall consider the driver to possess circular motion whenever it rotates continuously upon a fixed centre or axis; and in order to generalise still further, we shall suppose the reciprocating motion to be either rectilinear or circular; we shall in this manner be enabled to bring under one point of view a great variety of useful mechanical contrivances.

11. Circular may be converted into reciprocating motion by the aid of *escapements*.

An *escapement* consists of a wheel fitted with teeth which are made to act upon two distinct pieces or *pallets* attached to a reciprocating frame, and it is arranged that when one tooth escapes, or ceases to drive, the other shall commence its action. One of the most ancient forms is the following.

A sliding frame, A B, (Fig. 25.) is furnished with two projecting pieces at C and D, and within it is centred a wheel possessing three teeth, P, Q, and R, which tends always to turn in the direction indicated by the arrow.

Fig. 25.

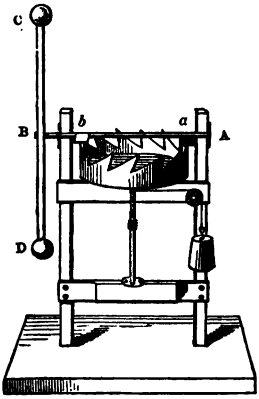


The upper tooth, P, is represented as pressing upon the projection D, and driving the frame to the right hand: when the tooth P escapes, the action of Q commences upon the other side of the frame, and the projection C is driven to the left hand. Thus the rotation of the wheel causes a reciprocating movement in the sliding piece, A B.

It is clear that the wheel must have 1, 3, 5, or some odd number of teeth upon its circumference.

12. The crown wheel escapement was invented for the earliest clock of which we possess any record.

Fig. 26.



The form of the wheel is that of a circular band, with large saw-shaped teeth cut upon one edge; the vibrating axis, A B, (Fig. 26.), carries two flat pieces of steel, *a*, *b*, called pallets, which project from the axis in directions at right angles to each other, and engage alternately with teeth upon the opposite sides of the wheel. Suppose the wheel to turn in the direction towards which the teeth incline, and let one of its teeth encounter the pallet *b* and push it out of the way; as soon as *b* escapes a tooth on the opposite side meets the pallet *a* and tends to bring the axis A B back again: thus a reciprocating action is set up, which will be very rapid unless A B is provided with a heavy arm, C D, at right angles to itself. Such an arm possesses *inertia*, so that its motion cannot be suddenly checked and reversed, and a recoil action is set up which materially subtracts from the utility of this contrivance. For it will be seen that the vibration of C D cannot be made to cease suddenly, and that the wheel must of necessity give way and recoil at the first instant of each engagement between a tooth and its corresponding pallet.

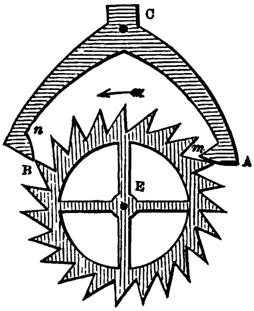
The more heavily C D is loaded at a distance from the axis the more slowly will the escapement work, and the greater will be the amount of the recoil.

Here we have an invention which has done good service to mankind. It was used in the first clock that was ever made: then it became an essential part of all watches, and now finally it is everywhere found in the kitchen jack for roasting meat.

The principle of this escapement is precisely the same as that of the preceding one; the number of teeth in the wheel must therefore be odd, or otherwise the axis A B must be set upon one side of the centre of the crown wheel.

13. The *Anchor Escapement* was invented by Dr. Hooke, and is almost universally adopted in the mechanism of pendulum clocks.

Fig. 27.



A wheel centred at E is provided with a number of teeth, and tends always to turn in the direction indicated by the arrow. (Fig. 27.)

A portion of this wheel is embraced by an anchor, A C B, centred at C, the extreme ends of which are formed into pallets, A *m* and B *n*: these pallets may be flat or slightly convex, but they are subject to the condition that the $\perp^r$ to A *m* shall pass below E, and the $\perp^r$ to B *n* shall pass between C and E. The point of a tooth is represented as escaping from the pallet B *n* after driving the anchor to the left hand; as soon as this tooth has escaped, another meets A *m*, and drives the anchor to the right hand, and thus the wheel can only proceed by causing a vibratory motion in the anchor, A C B.

The rapidity of this vibration may be very great, or it may be reduced by connecting the anchor with a much heavier body, such as the pendulum of a clock.

There is the same recoil experienced upon each swing of the pendulum as that which we noticed in the last article, and the contrivance is generally known as the "Recoil Escapement."

The exact character of the action which takes place between the pendulum of a clock and the scape wheel has been the subject of a long and interesting mathematical investigation: it is foreign to our purpose to discuss it here, but we may state generally the nature of the problem.

The going part of a clock consists of a train of wheels tending to move under the action of a weight or spring: if the last wheel of the train were left to itself, it would spin round with great velocity, and we should fail in obtaining any measure of time.

The escapement is one part of a contrivance for regulating the velocity of the train of wheels, but the escapement alone is not sufficient; we require further a vibrating body possessing *inertia*, the motion of which cannot be suddenly stopped or reversed.

Such a body is found in the pendulum, and a very intricate mutual action exists between the pendulum and the scape wheel. The function of the pendulum is to regulate and determine the periods and amount of onward motion in the scape wheel, whereas the office of the wheel is to impart such an impulse to the pendulum at each period of this onward movement as may serve to maintain its swing unimpaired, and may cause it to move with the same mathematical precision which would characterise the vibrations of a body swinging *in vacuo*, and uninfluenced by any disturbing causes.

14. The teeth in the wheel are sometimes replaced by pins, in which case the form of the anchor may be so altered that the action shall take place upon one side of the wheel. (Fig. 28.)

Fig. 28.

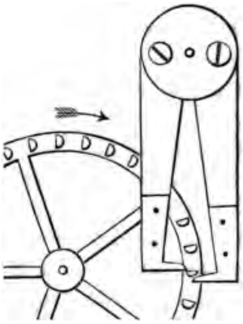
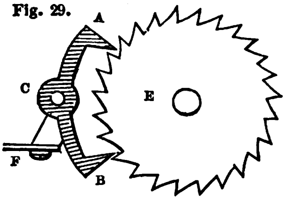


Fig. 29.



The recoil escapement may be used to obtain a rapid vibratory action, such as that of the hammer upon the bell of an alarum clock.

In a printing telegraph instrument it has been employed to control the rapidity of motion in a train of wheels, and the number of vibrations of the anchor are appreciated by listening to the musical note which it imparts to a vibrating spring.

The anchor A C B (Fig. 29.) is centred at C, and vibrates rapidly as the scape wheel E revolves; a strip of metal F carries on the oscillation to a steel spring which gives the note, and the velocity of the train can be regulated by an adjustable weight attached to the spring.

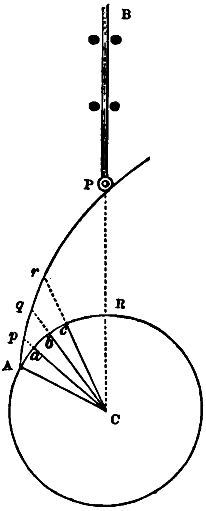
15. Circular may be converted into reciprocating motion by the aid of *cams*.

The term "*cam*" is applied to a curved plate or groove which communicates motion to another piece by the action of its curved edge.

The circular motion being uniform, the reciprocating piece may also move uniformly as a sliding bar, or its velocity may be varied at pleasure.

I. Let the direction of the sliding bar pass through the centre of motion of the cam plate; take C as this centre, B P the sliding bar, and A the commencement of the curve of the cam plate. (Fig. 30.)

Fig. 30.



The curve A P may be set out as follows:—

With centre C and radius C A describe a circle, and let B P produced meet its circumference in R.

Divide A R into a number of equal arcs A a, a b, b c, &c.

Join C a, C b, C c, &c. and produce them to p, q, r, &c. making a p, b q, c r, &c. equal to the desired movements of B P in the corresponding positions of the cam plate: the curve A p q r...P will be the curve required.

It may be represented analytically without any difficulty.

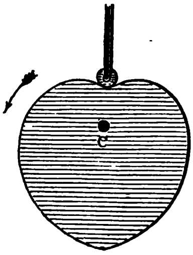
Thus let $CA = a$, $CP = r$, $PCA = \theta$, and let B P move so that $PR = m \cdot AR$

$$\therefore r - a = m \cdot AR = m a \theta$$

which is the equation to the spiral of Archimedes.

16. The *heart wheel* (Fig. 31.) has been very much used in machinery, and is formed by the union of two cams of the character just examined.

Fig. 31.



Its peculiar form allows the plate C to perform complete revolutions, and to cause thereby a reciprocating movement in the sliding bar.

A cam of this kind will only drive in one direction; the follower must therefore be brought back by the action of a weight or spring.

17. II. Let the direction of B P (Fig. 32.) pass upon one side of C: draw C R $\perp^r$ to B P produced, describe a circle of radius C R, and suppose the motion to begin when A coincides with R; as before, divide A R into the equal intervals A a, a b, b c, &c., but now draw $a\,p$, $b\,q$, $c\,r$, &c., tangents to the circle, and equal in length to the desired movements of B P during the corresponding periods of motion of the cam plate.

The curve A p q r ... P will be that required.

Fig. 32.

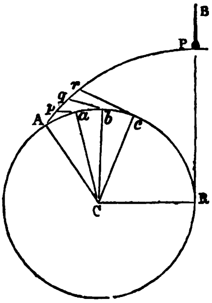
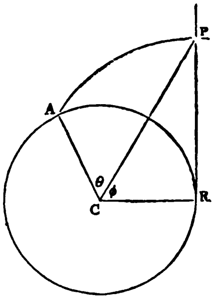


Fig. 33.



Its equation may be found as follows:—

$$\text{Let } CP = r,\ CA = a \text{ (Fig. 33.)}$$

$$ACP = \theta,\ PCR = \phi.$$

Suppose the linear velocity of A to be m times that of P, or that A R $= m$. R P,

$$\text{then } a\,(\theta + \phi) = m\,a \tan\phi$$

$$\text{But } \cos\phi = \frac{a}{r} \ \therefore\ \tan\phi = \sqrt{\frac{r^2}{a^2} - 1}$$

$$\therefore\ \theta + \cos^{-1}\frac{a}{r} = m\sqrt{\frac{r^2}{a^2} - 1}$$

Cor. Let $m = 1$, or A R $=$ R P,

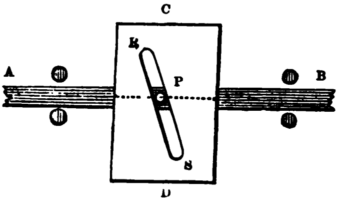
$$\therefore\ \theta + \cos^{-1}\frac{a}{r} = \sqrt{\frac{r^2}{a^2} - 1}$$

the equation to the involute of a circle. See Art. **79.**

It is evident that the curve A P would now be traced out by the end of a string unwound from the circle.

18. Hitherto we have considered the cam to be a plane curve or groove; but there is no such restriction as to its form in practice. Let us examine the following very simple case, as well as the extension of which it admits.

Fig. 34.

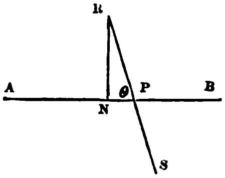


In Fig. 34, C D is a rectangle with a slit cut through it obliquely; a pin P, fixed to the sliding bar A B, works in the slit.

If the rectangle C D be moved in any other direction than that of the slit R S, it will also impart motion to the pin P.

1. Let C D be moved at right angles to A B; draw R N $\perp^r$ to A B, and let A P R $= \theta$. (Fig. 35.)

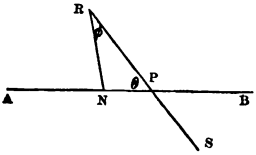
Fig. 35.



$$\text{Then } \frac{\text{velocity of plane}}{\text{velocity of bar}} = \frac{\text{R N}}{\text{N P}}$$
$$= \tan\theta.$$

2. Let C D move in a direction inclined at an $\angle\,\phi$ to R S; draw R N in this direction. (Fig. 36.)

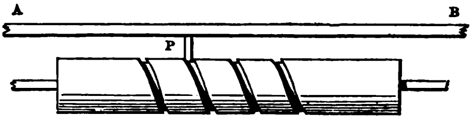
Fig. 36.



$$\text{Then } \frac{\text{velocity of plane}}{\text{velocity of bar}} = \frac{\text{R N}}{\text{N P}}$$
$$= \frac{\sin\theta.}{\sin\phi}$$

19. Now let C D be wrapped round a cylinder; it will form a screw thread (Fig. 37.), and the revolution of the cylinder upon its axis will be equivalent to a motion of the rectangle at right angles to the bar, in the manner shown in the preceding article; we shall, therefore, have by the arrangement in the figure a continuous uniform rectilinear motion of the bar A B during the revolution in the cylinder upon which the screw thread is traced.

Fig. 37.

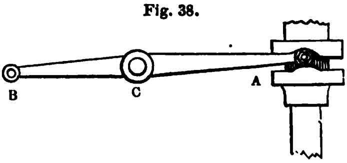


If the pitch of the screw be constant, the motion of P B will be uniform, and any change of velocity may be introduced by a proper variation in the direction of the screw thread.

If the screw be changed into a circular ring, A B will not move at all.

20. The annexed is a very common form of cam where a small rapid motion of a lever is required; C being a centre of motion, the lever A C B will move as soon as the stud reaches that portion of the ring which departs from the circular form.

Fig. 38.



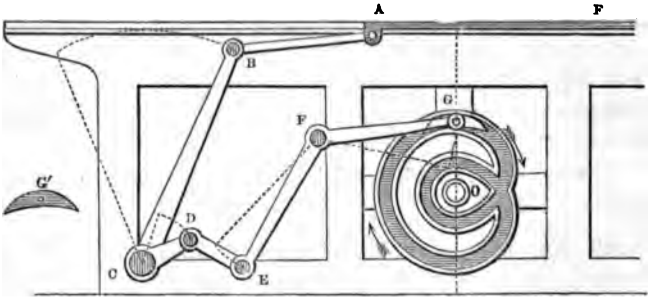
21. It is then a matter of indifference whether the cam be a groove traced upon a flat plate or a spiral helix running round a cylinder. In the first case motion ensues when the groove departs from the circular form, and the distance from the centre varies; in the second case motion ensues the moment the groove begins to deviate from the form of a ring whose plane is $\perp^r$ to the axis.

22. We subjoin an example, devised some twenty years ago, in which a reciprocating movement is imparted to a frisket frame in printing machinery, and it will be presently seen that the required result can be obtained in a much more simple manner.

The use of a cam plate allows of an interval of rest at each end of the motion, and enables the printer to obtain an impression, and to place a fresh sheet of paper upon the form.

F is the reciprocating frame attached to the combination of levers G F E D C B by the link A B. (Fig. 39.)

Fig. 39.



At the end of the lever, F G, is a sliding pin which travels along the grooves in the flat plate centred at O, and determines the angular motion of the levers of the vertical dotted line through O.

Where the groove is circular, which occurs in those portions which are to the left hand of the vertical dotted line, the levers remain at rest, and they change into the position shown by the dotted lines when the sliding pin passes from the outer to the inner channel. The pin is elongated in form, as shown at G′, and is thus capable of passing across the intersections of the groove.

23. Precisely the same character of movement may be obtained by the aid of a helical groove traced upon a revolving drum; the intervals of rest occur when the groove assumes the form of a flat ring, whose plane is perpendicular to the axis of the drum.

A right- and left-handed screw thread is traced upon the worm barrel, A B, (Fig. 40.), which revolves in one uniform direction: a pin attached to the table of a printing machine follows the path of the groove upon the barrel, and its form is elongated so as to enable it to pass in the right direction at the points where the grooves intersect.

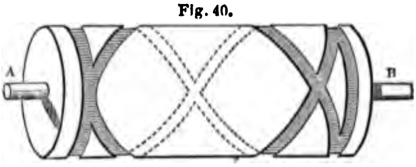


Fig. 40.

The interval of rest commences with the entry of the pin into the flat ring at either end of the barrel, and may be made to occupy the whole or any part of a revolution of A B, according as the grooves enter and leave the ring at the same or different points.

This construction dispenses with the complicated system of levers, which constitutes such a serious defect in the other arrangement.

24. Mr. Napier has patented an invention which causes the interval of "rest" to endure beyond the period of one revolution of the barrel. (Fig. 41.)

At the entrance to the circular portion of the groove a moveable switch is placed, and it is provided that the switch shall be capable of twisting a little in either direction upon its point of support, and also that the pin upon which the switch rests shall admit of a small longitudinal movement parallel to the axis of the barrel, the pin itself being urged constantly to the right hand by the action of a spring.

Fig. 41.

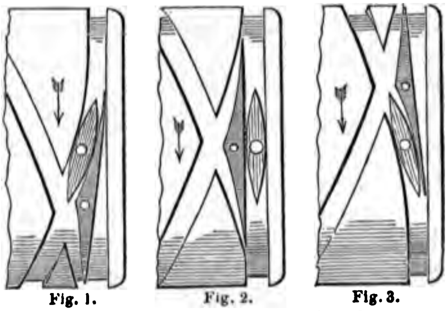



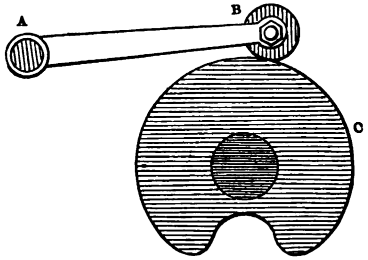
Fig. 1. Fig. 2. Fig. 3.

In Fig. 1. the shuttle is seen entering the circular portion of the groove, and twisting the switch into a position which will allow the shuttle to meet it again, as in Fig. 2., and to make a second journey round the circular ring.

The spring which presses the point of support of the switch to the right hand will now cause it to twist by means of the reaction which the passing pin affords, and the consequence will be that the switch will be left in the position shown in Fig. 3., and will guide the shuttle into the helical portion of the groove. Thus the period of rest will be that due to about one and two-thirds of a revolution of the barrel.

25. Cams are employed when it is required to effect a movement with extreme precision. Thus in the "Times" printing machine the sheet of paper starts upon its journey to meet the type at a particular instant of time; an error of one-twelfth of a second would cause the impression to deviate nearly a foot from its correct position, and would throw two columns of letter-press off the sheet of paper. The accuracy with which the sheet is delivered is therefore very remarkable, and is ensured by the assistance of the cam represented in Figure 42.

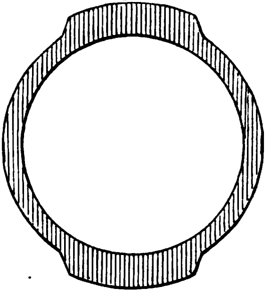
Fig. 42.



As the plate, C, revolves, the lever, A B, drops into the hollow of the plate, and determines the fall of the roller, which starts the paper upon its course to the printing cylinder.

26. Cams are admirably adapted to the production of a short rapid motion, with intervals of rest.

Fig. 43.

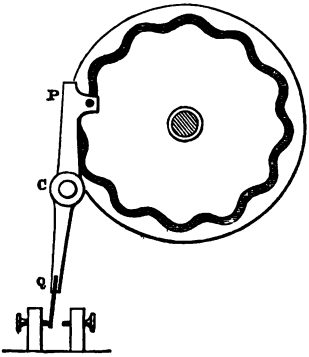


In the expansive working of a steam-engine there are two positions of rest for the valve which regulates the admission of steam into the slide case, and it is desirable to move the valve as rapidly as possible from one position to the other.

Hence the form of an *expansion cam*, as indicated in Figure 43.

27. Where the cam plate is required to effect more than one double oscillation of the sliding bar during each revolution, its edge must be formed into a corresponding number of waves.

Fig. 44.

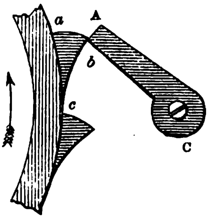


There is an example in telegraph commutators (Fig. 44.), the interruptions of the current being caused by the vibrations of a lever, P C Q, centred at C, and whose angular position is determined by the pin at one end of it.

As the wheel revolves it can impress any given number of double oscillations upon the lever.

28. In the striking part of a large clock the hammer may be raised by a cam, and be then suffered to fall abruptly.

Fig. 45.

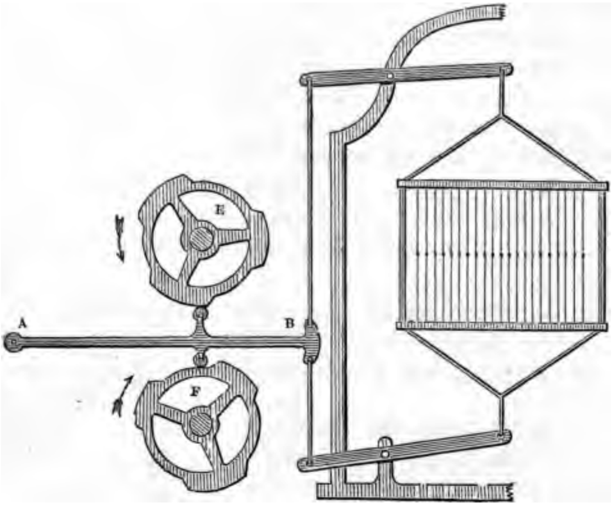


The figure represents the cam devised for the Westminster clock: the hammer rises and falls with the lever, A C (Fig. 45.), and the cam is so formed that its action commences at the extremity of the lever, and never departs sensibly from the same point; the cam, *a b*, is a circle whose centre is at the point of intersection of the tangents to the rim of the wheel at the points *a* and *c*.

29. We remark, in conclusion, that when the mechanic causes the moving body to be influenced by a pin which exactly fits the groove along which it travels, there is no question but that the moving body will take the exact position determined by the pin; on the other hand, where the cam is merely a curved plate pushing a body before it, there is no certainty that this body will return unless it be brought back by a weight or spring. Hence it arises that double cams have sometimes been employed in machinery, and we take the annexed example from an early form of power-loom.

A B is the treadle (Fig. 46.), E and F are the cam wheels or tappets, which revolve in such relative positions that the projections and hollows are exactly opposite to each other.

Fig. 46.



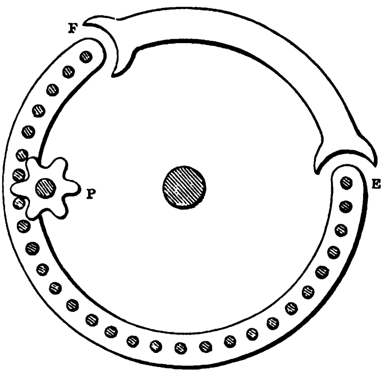
The treadle, A B, is alternately elevated and depressed, and the threads of the warp are opened to permit the throw of the shuttle.

30. Mangle wheels form a separate class of contrivances for the conversion of circular into reciprocating motion.

A *mangle wheel* is usually a flat plate or disc furnished with pins projecting from its face; these pins do not fill up an entire circle upon the wheel, but an interval is left, as shown at F E. (Fig. 47.)

A pinion, P, engages with the pins, and is supported in such a manner as to allow of its shifting from the inside to the outside, or conversely, by running round the pins at F and E.

Fig. 47.

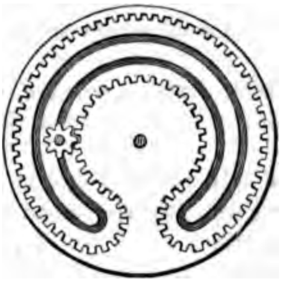


The pinion, P, always turns in the same direction, and the direction of rotation of the mangle wheel is the same as that of P when the pinion is inside the circular arc, and in the opposite direction when the pinion passes to the outside.

By referring to the chapter upon the teeth of wheels, we may see that the inner and outer pitch circles coincide in the case of a pin wheel, and therefore that the rotation of the mangle wheel is precisely the same in both directions.

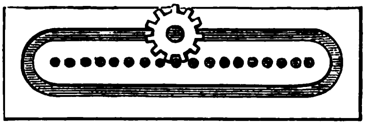
31. If the pins be replaced by a curved ring furnished with teeth, the mangle wheel will move more rapidly when the pinion is upon the inside circumference, (Fig. 48.), and by giving certain arbitrary forms to this annulus, the velocities of advance and return may be modified at pleasure.

Fig. 48.



32. The mangle wheel may be converted into a *mangle rack* by placing the pins or teeth in a straight line. (Fig. 49.)

Fig. 49.



Here the pinion must be so suspended as to allow of its shifting from the upper to the under side of the rack.

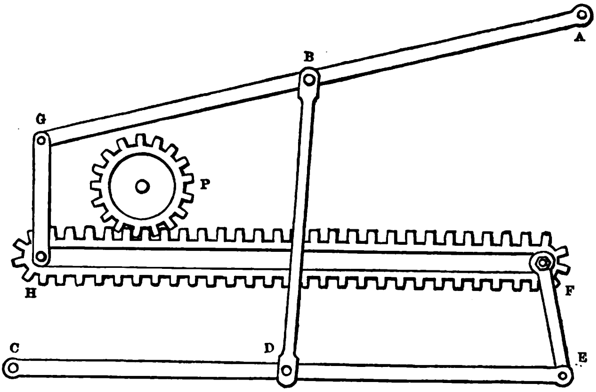
33. Sometimes the pinion is fixed, and the rack shifts laterally.

An excellent form of this arrangement was introduced by Mr. Cowper, and serves to give a reciprocating movement to the table in his printing machine.

The rack, H F, (Fig. 50.) is attached to the system of bars in the manner exhibited in the diagram. A and C are centres of motion, and are the points where the bars are attached to the table. A G and C E are bisected in B and D, and are joined by the rod, B D; the rack, H F, is attached to the bars, A G and C E, by the connecting links, G H and F E.

The precise value of the contrivance will be understood upon referring to the section upon Parallel Motion, and it will be seen that when the pinion has pushed the rack to either end of its path, the bars will move together, and will *shift H F in a* direction parallel to its length, and will thereby cause it to change from one side to the other of the pinion.

Fig. 50.



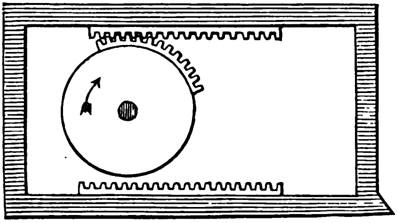
By reason of the great weight of the table, and the rapidity with which it moves, it would be quite unsafe to leave the rack and pinion in the present unassisted condition: a guide roller determines the position of the pinion relatively to the rack, while the rack itself shifts laterally between guides.

But as, theoretically, the rods would cause H F to move always in a direction parallel to itself; so, practically, they enforce the desired movement in the path of the guides with as little loss of power as possible.

34. If it be required that the reciprocation shall be intermittent, i. e. that there shall be intervals of rest, we may employ a segmental wheel and a double rack. (Fig. 51.)

The teeth upon the pinion engage alternately with those upon either side of the sliding frame, A B, and the motion is of the character required. The intervals

Fig. 51.

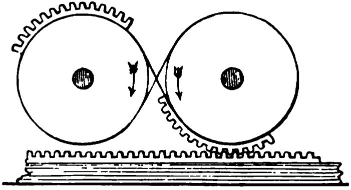


of rest are equal, and are separated by *equal* periods of time.

A pin upon the wheel and a guide upon the rack will ensure the due engagement of the teeth.

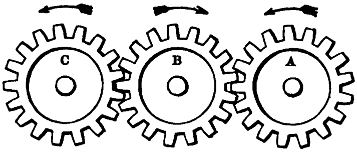
35. A mechanical equivalent to the above is found in the use of two segmental wheels and a single rack. (Fig. 52.) The segments must be equal, but they may be placed in different relative positions; and, as a consequence, the intervals of rest may be separated by *unequal* periods of time.

Fig. 52.



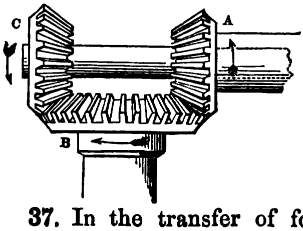
36. Combinations of toothed wheels, or something equivalent thereto, may be used in the conversion which we are considering. Let A, B, C (Fig. 53.) be three wheels in gear; then A and B turn in opposite directions, but A and C turn in the same directions.

Fig. 53.



If, however, the wheels A and C (Fig. 54.) be bevelled wheels, and be arranged with reference to B, as in the figure annexed, they will no longer turn in the same, but in opposite directions.

Fig. 54.



There are many contrivances founded upon these simple propositions in the geometry of motion, of which we select the most prominent examples; premising at the same time one or two general observations.

37. In the transfer of force by machinery the moving power is carried from one piece of shafting to another, throughout the whole length and breadth of the factory, it passes from point to point, enters each separate machine, and gives movement to all the parts which are prepared for its reception.

Now it must be remembered that the engine is never reversed, and that the power flows on in one uniform direction.

Take the case of a machine for planing iron: here the principal movement is that of a heavy table sliding forwards and backwards, and carrying the piece of metal which is the subject of the operation.

There are two methods of obtaining the desired result: the power may be poured, as it were, into the machine by a stream running always in one direction, and the reciprocation may be provided for by the construction of the internal parts, or the flow of the stream may be reversed by some intermediate arrangement external to the machine itself.

38. The former method is that usually adopted, and we shall first examine those machines where the reciprocation depends upon the internal construction of the moving parts.

The power is derived from the shafting by means of a band passing over a drum on the main shaft and over one of the three pulleys, E, I, F, at the entrance into the machine. (Fig. 55.)

In the annexed figure, which shows the principle of the movement adopted by Collier in his Planing Machines, and subsequently much used by other makers, the pulley E is keyed to a shaft terminating in the wheel A′; I is an idle pulley riding loose upon the same shaft; F is a pulley fixed to a pipe, through which the shaft connecting E and A′ passes, and which terminates in the wheel A.

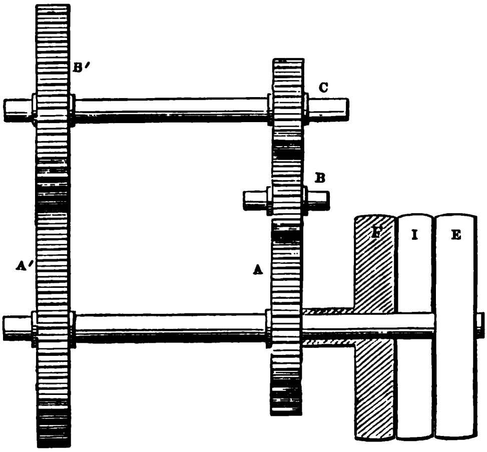
B′ C is a second shaft which carries the toothed wheels, B′ and C.

B is an intermediate wheel riding upon a separate stud.

When the band drives the pulley E, we observe that A′ and

B′ turn in opposite directions; whereas the motion is reversed when the band is shifted to F, for in that case A and C turn in the same direction. When the driving band is placed upon I the machine remains at rest.

Fig. 55.



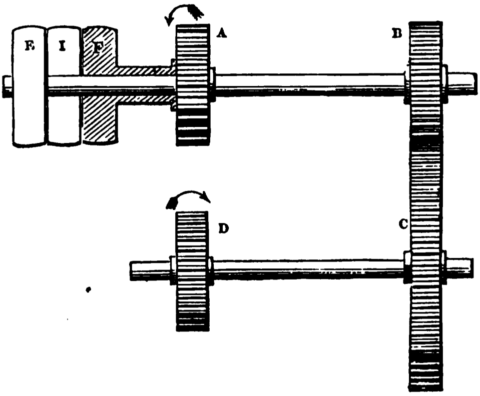
The rotation of B′ C may be made much more rapid in one direction than in the other, and the construction is therefore very valuable in machinery for cutting metals.

The slow movement occurs while the cutting tool is removing a strip of metal, and the return brings the table rapidly back into the position suitable for a new cut.

39. This movement, slightly modified, is adopted in Collier's planing machine, and in those of other makers.

We give so much of the machine as will explain the method of reversing the motion of the table. (Fig. 56.) When the strap is upon the pulley F, the wheel A turns in one direction. When the strap is upon the pulley E, the motion passes to B, which turns with E, and thus the axis, C D, is made to revolve in the opposite direction with a reduced velocity. The wheels A and D both engage with another wheel not shown in the drawing, which actuates the table, and the reversal takes place according as the moving power resides in A or D.

Fig. 56.

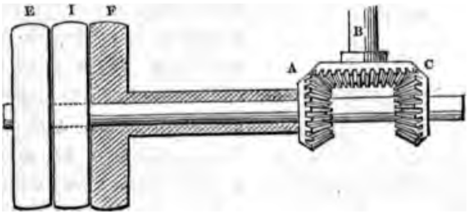


40. Mr. Whitworth's reversing motion is the following, (Fig. 57.) —

As before, there are three pulleys, E, I, and F, whereof I is an idle pulley, and rides loose upon the shaft; E is keyed to the shaft, which terminates in the bevil wheel C, and F sits upon a pipe through which the shaft connecting E and C passes, and which terminates in the bevil wheel A.

B is a bevil wheel at the end of the screwed shaft, which gives a reciprocating movement to the table.

Fig. 57.



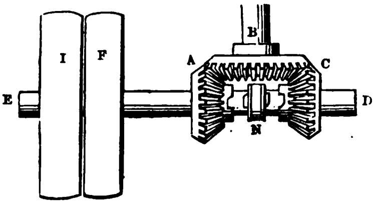
It is clear that the motion of the wheel B is reversed when the driving strap is shifted from E to F.

This is an example of the second case in Art. **36.** and differs from that last considered in not permitting the motion of B to be more rapid in one direction than in the other.

41. In some screwing machines a rapid action of reversal is obtained without shifting the driving strap.

Here there is only one working pulley, F, and C is the wheel whose motion is to be reversed. (Fig. 58.)

Fig. 58.



The driving pulley is shown upon the line E D; it may, however, be placed upon the axis of the wheel B, in which case the reversal will be found in the shaft E D, instead of in C.

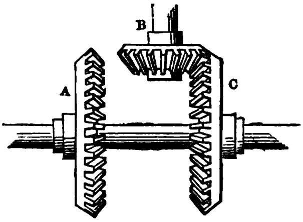
Both the wheels A and C ride loose upon the shaft, and derive their motion alternately from E D by means of a shifting clutch, N.

When N fixes C to the shaft, the motion of C is the same as that of F; but when N fixes A to the shaft, the motion of C is in the opposite direction to that of F, and thus a reversal of the wheel C is effected.

42. In spinning machinery a reversing motion is commonly obtained as follows: —

(Fig. 59.) B is connected with the driving shaft, and the bevil wheels, A and C, are keyed to the shaft whose motion is reversed; the interval between A and C is enlarged so that B can only be in gear with one of these wheels at the same time, and the shaft, A C, is shifted longitudinally to allow B to engage with A and C alternately.

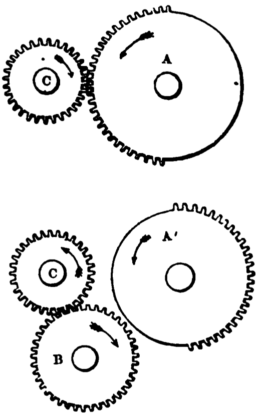
Fig. 59.



This is again an example of the second case in Art. **36.**

43. Mr. Whitworth has proposed the subjoined arrangement for the reversal in a machine for cutting screws: we take it as an example of the use of segmental wheels, which, however, should always be avoided if possible. There is only one driving pulley, and two segmental wheels are keyed upon the driving shaft. They are close together in the machine, and for the sake of the explanation we have placed one above the other. The object is to effect the reversal of a shaft C: the segmental wheels A and A′ have teeth formed round one half of each circumference, and the toothed segments are in situations opposite to each other, as in Figure 60.

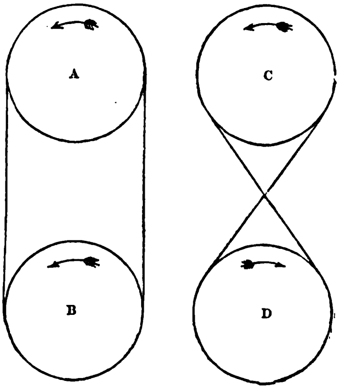
Fig. 60.



When the action of A ceases that of A′ begins, and we have the wheels A and C, or the wheels A′, B, and C alternately in action, *i. e.*, we have a reciprocation of C. This is a direct example of the first case in Art. **36.**

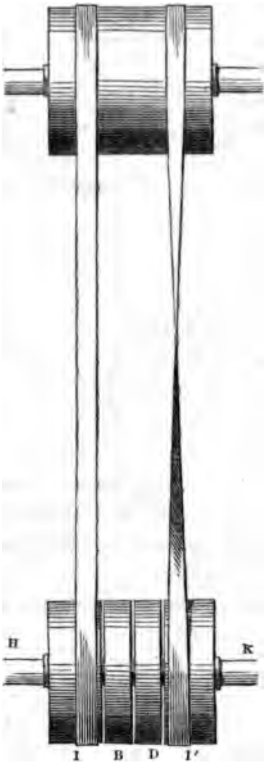
44. Where the reciprocation is effected by a contrivance external to the machine itself, two driving bands may be employed: of these one is crossed, and the other is open, as shown in Fig. 61., and it is apparent that the lower discs B and D will turn in opposite directions, although they derive their motion from A and C, which rotate always in the same direction.

Fig. 61.



45. The form which the arrangement assumes in practice is shown in Fig. 62., where one of the driving bands is represented as crossed, and the rotation of the shaft, H K, is derived from each band alternately.

Fig. 62.



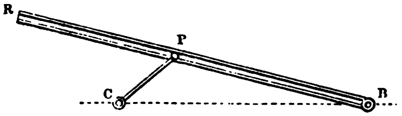
There are four pulleys, whereof I and I' are loose upon the shaft, and are twice as broad as B and D, which are working pulleys.

The bands are shifted by two forks, and remain always at the same distance from each other. In the figure the bands are both upon the idle pulleys, and H K remains at rest. When the bands are shifted to the right, the open strap drives B, and the crossed one remains upon I': when the bands are shifted to the left, the crossed strap drives D, and the open one passes to I. Thus the shifting of the band effects the required reversal of the shaft H K.

The motion in either direction is the same, but it may be varied by placing drums of unequal size upon the upper shaft.

46. There is yet one most ancient contrivance for changing circular into reciprocating motion, which will repay the trouble of analysing it. In the form exhibited in Art. **48.** it was used by the early Greek astronomers to represent *mechanically* the motion of the Moon.

Fig. 63.



Let the arm, C P, (Fig. 63.) be centred at C, and convey motion to the grooved arm, B R, by means of a pin, P, which fits into the groove.

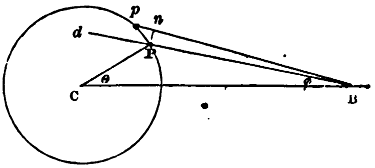
If C P be less than C B the uniform circular motion of C P will cause a variable reciprocating motion in B R.

Let C (Fig. 64.) be the centre of the circle described by P, P p a small arc, and P n a $\perp^{r}$ upon B p.

Let $\mathrm{PCB} = \theta$, $\mathrm{PBC} = \phi$, $\mathrm{CP} = a$, $\mathrm{CB} = c$.

Then
$$\tan\phi = \frac{a \sin\theta}{c - a\cos\theta}$$

Fig. 64.



which gives the position of B P corresponding to that of the driving arm.

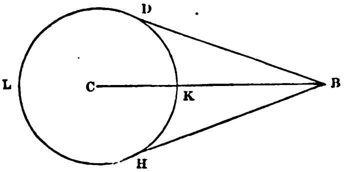
Again
$$\frac{\angle^{r}\text{ vel. of BP}}{\angle^{r}\text{ vel. of CP}} = \frac{\mathrm{P}n}{\mathrm{PB}} \div \frac{\mathrm{P}p}{\mathrm{CP}} = \frac{\mathrm{P}n}{\mathrm{PB}} \times \frac{\mathrm{CP}}{\mathrm{P}p}$$

But
$$\begin{aligned} \mathrm{P}n &= \mathrm{P}p \cos p\mathrm{P}n \\ &= \mathrm{P}p \cos d\mathrm{PC} \\ &= \mathrm{P}p \cos(\theta + \phi) \end{aligned}$$

$$\therefore \quad \frac{\angle^{r}\text{ vel. of BP}}{\angle^{r}\text{ vel. of CP}} = \frac{\mathrm{CP}\cos(\theta+\phi)}{\mathrm{PB}}$$

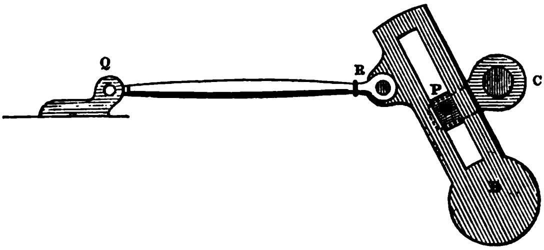
If we draw B D, B H, tangents to the circle described by P, it will be evident that the times of oscillation of the arm will be unequal, and will be in the same proportion as the lengths of the arcs D L H, D K H. (Fig. 65.)

Fig. 65.



47. This contrivance has been used to give motion to the table in a shaping machine, and effects a quick return.

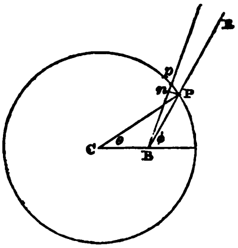
Fig. 66.



The diagram (Fig. 66.) will indicate the nature of that part of the machinery which imparts motion to the table.

48. If C P be greater than C B, there will be no reciprocation, but the uniform circular motion of C P will give rise to a variable circular motion in B R, and thus *indirectly* we may effect a reciprocating movement with a quick return. (Fig. 67.)

Fig. 67.



As before, let C be the centre of the circle described by P.

$$\text{CP} = a,\ \text{CB} = c$$

$$\text{PCB} = \theta,\ \text{PBD} = \phi$$

Then $$\tan\phi = \frac{a\sin\theta}{a\cos\theta - c}$$

And $$\frac{\angle^{r}\text{ vel. of BP}}{\angle^{r}\text{ vel. of CP}} = \frac{\text{P}n}{\text{PB}} \div \frac{\text{P}p}{\text{CP}}$$

$$= \frac{\text{P}p\cos\text{C}p\text{B}}{\text{PB}} \times \frac{\text{CP}}{\text{P}p}$$

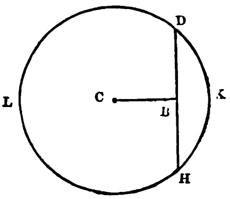
$$= \frac{\text{CP}\cos\text{CPB}}{\text{PB}}$$

If C B, and $\therefore$ the angle C P B, be small we have cos C P B nearly $= 1$, and $\angle^r$ vel. of B P $\propto \dfrac{1}{\text{P B}}$ nearly.

The angular vel. of B P will be equal to that of C P when C P . cos C P B $=$ B P, or when C B P is a right angle.

In the circle described by P draw D H $\perp^r$ C B, then the times of a half revolution of B P will be in the proportion of the arcs D K H and D L H. (Fig. 68.)

Fig. 68.



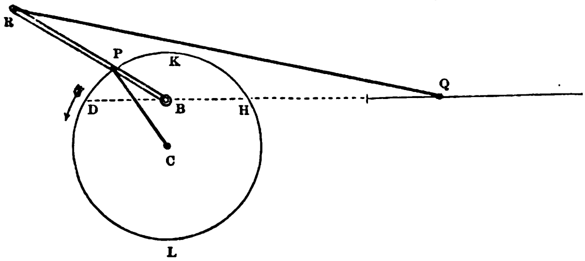
If B P be made to carry a link, R Q, as in the case of the crank and connecting rod, the linear motion of Q will be the same in amount as if B R revolved uniformly, but the periods of each reciprocation will in general be different.

The difference in the times of oscillation will depend upon the direction of the line in which Q moves.

The best position for that line is in a direction $\perp^r$ to C B: a little consideration will show that the times of oscillation are always as the arcs D K H and D L H, and that the inequality between these arcs is greatest when D H is $\perp^r$ to C B, and diminishes to zero when D H passes through C B.

49. We have now an arrangement very suitable for effecting a quick return of the cutter in a shaping machine. (Fig. 69.)

Fig. 69.

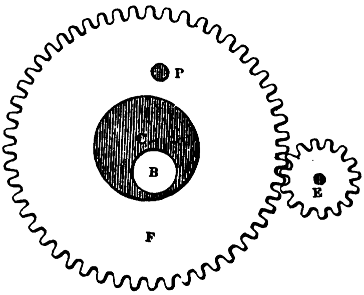


Let one end of a connecting rod be made to oscillate in a line $\perp^r$ C B, or nearly so, and let the crank B R be driven by an arm, C P, which revolves uniformly in the direction of the arrow, we at once perceive that Q will advance slowly and return quickly, the periods of advance and return being as the arcs D L H and D K H.

50. Such a direct construction is not very convenient for the transmission of force, and it has been so modified by Mr. Whitworth in his Shaping Machine, that the principle remains unchanged, while the details of the moving parts have undergone some transformation.

The object of the machine is analogous to that recently explained: a cutter is advanced slowly forward while doing its work, and returns rapidly when the cut has been accomplished.

Fig. 70.

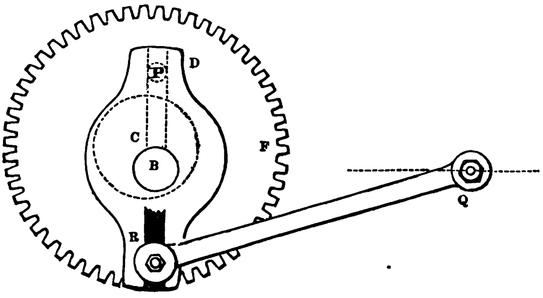


The arm, C P, (Fig. 70.) is obtained indirectly by fixing a pin, P, upon the face of a plate, F, which rides loose upon a shaft, C, and is driven by a pinion, E.

As the wheel F revolves upon its axis, the pin moves round C, and remains at a constant distance from its centre.

A hole, B, is bored in the shaft, C, (Fig. 71.), and serves as a centre of motion for a crank piece, D R: the connecting

Fig. 71.



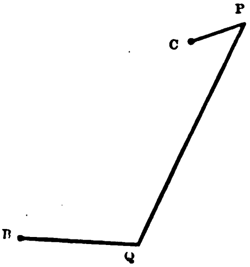
rod, R Q, is attached to one side of this crank piece, and the pin, P, works in a groove upon the other side. Thus Q oscillates and returns more rapidly than it advances; the length of path of Q depends upon the distance of R from B.

51. It remains for us to consider some circumstances of motion which result from a modification of the crank and connecting rod.

The point Q, in Art. 4., may be made to oscillate in a circular arc by fixing it to the end of a lever, B Q, which is moveable about a centre at B. (Fig. 72.)

We have then the celebrated combination of levers which was introduced by Lord Stanhope into the Printing Press.

Fig. 72.



52. The conditions which will cause a reciprocating movement in B Q are very simple: we have to provide that C P and P Q shall come into a straight line before B Q and P Q have the power to do so. (Fig. 73.)

There are two positions in which C P Q straightens into one line; and we derive the corresponding conditions that

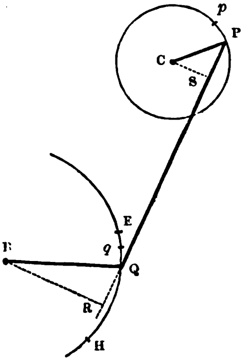
$$CB + BQ \text{ is } \urcorner\ PQ + CP$$

and $CB - BQ$ is $\angle\ PQ - CP$.

The points E and H, where the oscillation of Q terminates, result when C P Q becomes a straight line,

$$\therefore CE = PQ - CP$$
$$CH = PQ + CP.$$

Fig. 73.



53. The most important matter connected with the motion of CP and BQ is a comparison of their angular velocities.

Draw CS, BR $\perp^{rs}$ upon the direction of PQ, and let P and Q move to p and q respectively during the smallest considerable interval at the beginning of the motion. (Fig. 73.)

Then the resolved part of the motion of Q in direction QP

$$\begin{aligned} &= Qq \cos PQq \\ &= Qq \sin BQR \\ &= Qq \times \frac{BR}{BQ} \\ &= BR \times \frac{Qq}{BQ} \\ &= BR \times \text{angle } QBq. \end{aligned}$$

So also the resolved part of the motion of P in direction $QP = CS \times \text{angle } PCp$.

But in the first instant of motion these resolved parts are equal to each other.

$$\therefore\ BR \times \text{angle } QBq = CS \times \text{angle } PCp$$

$$\therefore\ \frac{\text{angle } QBq}{\text{angle } PCp} = \frac{CS}{BR}$$

$$\text{or}\quad \frac{\angle^{r} \text{ vels. of } BQ}{\angle^{r} \text{ vels. of } CP} = \frac{CS}{BR}$$

We shall hereafter comprehend the value of this proposition, with which we conclude the present chapter.

CHAP. II.

ON THE CONVERSION OF RECIPROCATING INTO CIRCULAR MOTION.

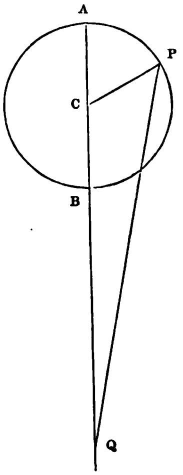
54. It has been shown that the motion of a point in a circle results from the combination of two reciprocating movements in lines at right angles to one another, and that circular may be converted into reciprocating motion by the suppression of one of these movements.

The reconversion of reciprocating into circular motion is not a problem of the same kind, as we now require the creation of a movement, instead of its suppression: such a creation is impossible in a strict mathematical sense, but is practically attainable by mechanical construction.

The circular motion may be that of a point, or it may be the motion of a revolving piece which turns always in one direction.

55. If a point, P, be required to describe a circle under the influence of another point Q oscillating in a straight line, it may be placed at the end of an arm or crank centred at C, and connected with Q by a rod, P Q. (Fig. 74.)

Fig. 74.



Suppose Q to move in a straight line pointing to C. It is evident that Q can push P before it, or can draw P after it, except in the two positions where C P and P Q come into the same straight line.

Also the motion of P must be circular.

The two points, A and B, where the tendency to motion dies away, are called the dead points, and P must be made to pass through them without the aid of Q.

In the steam-engine, where the reciprocating motion of the piston connected with Q gives rotation to a shaft whose axis passes through C, a fly wheel or heavy revolving body may carry P through those portions of its path near to A and B, and thus the engine may work smoothly and evenly.

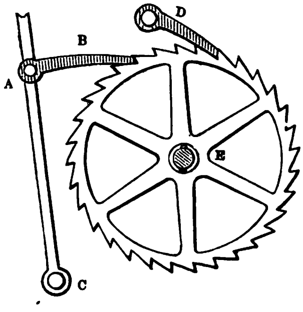
In marine engines, where the fly wheel is not admissible, and where the engine must admit of being readily started in any position, two separate and independent pistons give motion to the crank shaft. In this case the two cranks are placed at right angles to each other, so that when one crank is in a bad position the other is in a good one.

The same plan holds in the construction of locomotive engines.

56. If the motion is to be that of a wheel turning about its centre, we may suppress one half of the reciprocating movement, and let the other half always push the wheel in the same direction: this is the principle of a *ratchet wheel*, or the reciprocating piece may be of the form shown in escapements which produce a recoil, and its pallets will then act upon opposite sides of the wheel, and push it always in one uniform direction.

57. A wheel provided with pins or teeth of a suitable form, and which receives an intermittent circular motion from some vibrating piece, is called a ratchet wheel. (Fig. 75.)

Fig. 75.



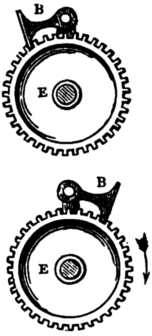
Let E represent the ratchet wheel furnished with teeth shaped like those of a saw: the driver is a click or paul, A B, jointed at one end, A, to a moveable arm, A C, which has a vibrating motion upon C as a centre.

As A C moves to the right hand the click, B, pushes the wheel before it through a certain space; upon the return of A C, the click, B, slides over the points of the teeth, and is ready again to push the wheel through the same space as before, being in all cases pressed against the teeth by its weight or by a spring. A detent, D, prevents the wheel from receding, while B is moving over the teeth.

In this way the reciprocating movement of A B is rendered inoperative in one direction, and the circular motion results from the suppression of one half of the reciprocating movement. The wheel, E, and the vibrating arm, A C, are often centred upon the same axis.

The usual form of the teeth is that given in the figure, and the result is that the wheel can only be driven in one direction; but in machinery for cutting metals it is frequently desirable to drive the wheel indifferently in either direction; in that case Mr. Whitworth adopts the annexed construction. (Fig. 76.) The ratchet wheel has radial teeth, and the click, B, can take the two positions shown in the figure, and can drive the wheel in opposite directions.

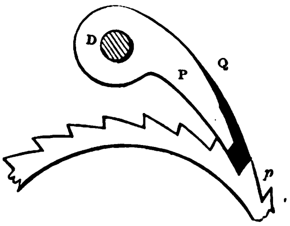
Fig. 76.



58. Hitherto there has been nothing to lead us to suppose that the advance of the ratchet wheel can be made to differ from some exact multiple of the space between two consecutive teeth.

Suppose, however, that it were required to advance the wheel by the space of half a tooth: two clicks, D P, D Q (Fig. 77.) should be fixed at B, the difference between their lengths being half the interval between the points p, q. The clicks

Fig. 77.



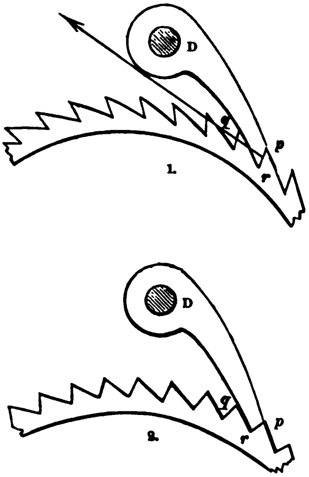
will engage with the teeth alternately, and the wheel will move as if it had twice as many teeth and were worked by one click.

With three clicks differing in length by one-third of the interval $p\,q$, the wheel would be equivalent to another with three times as many teeth, and so the wheel may be practically equivalent to another with a greatly increased number of teeth.

This is a useful contrivance, as it is not advisable to multiply the teeth in a ratchet wheel; they become liable to break and wear away, the click occasionally slips, and the action is uncertain.

59. As regards the action between the teeth and the detent, we observe that the wheel must tend to hold the detent down by the pressure which it exerts, and that it will do so as long as the line of pressure on the surface, $p\,r$, falls below the centre of motion D. (Fig. 78.) If the angle $q\,r\,p$ were opened out much more, as shown in Fig. 2., the $\perp^{r}$ upon $p\,r$ might rise above D, and the detent would then fail to hold the wheel.

Fig. 78.



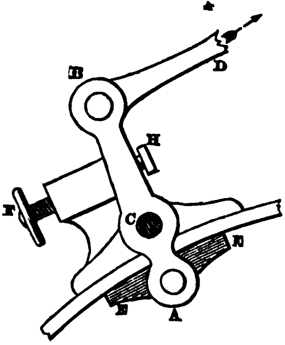
Further, the click has to return by slipping over the points of the teeth; the condition for this result is that the $\perp^{r}$ to the surface $q\,r$ shall fall between D and the centre of the wheel.

Where very little force is required to hold the wheel, and the exact position is of consequence, as in counting machinery, the teeth may be pins, and the detent may be a roller pressed against them by a spring.

60. The ratchet wheel has been greatly used for obtaining an advance of the piece of timber in sawing machinery. A substitute has lately been found in a very ingenious contrivance constructed as follows:—

An arm, A B, (Fig. 79.) centred at C, rides upon a saddle which rests upon the outer rim of a wheel; a piece, E E, is attached to one end of the arm and admits of being pressed firmly against the inside of the rim of the wheel which carries the saddle.

Fig. 79.



It is clear that when the end, B, of the arm, A C B, is pulled to the right hand, the rim of the wheel will be grasped firmly between the saddle and the piece, E E, and that the pull in B D will move the saddle and wheel together, as if they were made in one piece. When B is pushed back a stop prevents B C A from turning more than is sufficient to loosen the hold of E E, and the saddle slides upon the rim through a small space.

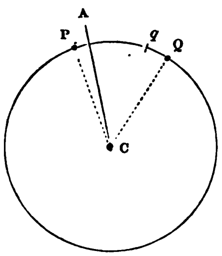
In this manner the action of a ratchet wheel is imitated, and, by properly regulating the amount of motion communicated by the link B D, we obtain an equivalent for a ratchet wheel with an infinite number of teeth.

A screw, F, may be employed to bring up a stop, H towards the arm, A C B, and thus to prevent the arm from twisting into the position which gives rise to the grip of E E. The saddle will then slide in both directions without imparting any motion to the wheel, a result which is obtained in an ordinary ratchet wheel by throwing the click off the teeth.

61. In the use of ratchet wheels it is often convenient to give a certain definite amount of motion to the arm which carries the click, and yet to control the amount received by the wheel.

Let C A (Fig. 80.) be a rod centred at C, P and Q two pins in a circle which vibrates through the angle P C Q.

Fig. 80.

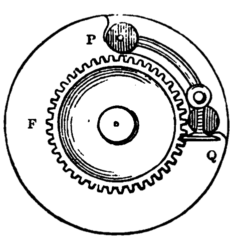


It will be seen that if P and Q embrace the rod closely upon opposite sides the whole vibration of the circle will be imparted to C A.

If, however, Q be moved to *q*, the arm C A will be pushed to Q by the pin P when moving to the right, but will only return as far as Q can carry it, *i. e.* to *q*, and the vibration will take place through an ∠ Q C *q* instead of an ∠ Q C P, and in this way, by separating P and Q, the motion of A C may be reduced till it ceases altogether.

62. This device is put into practice by Mr. Whitworth, who derives from it a method of advancing the cutting tool in a planing machine.

Fig. 81.

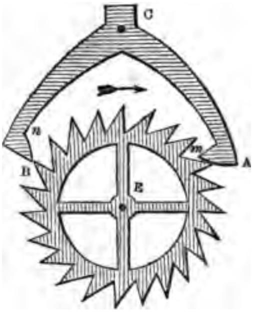


A disc F, (Fig. 81.) a ratchet wheel R, and an arm carrying a click are centred upon the same axis, but can move independently of each other. The disc F has a circular slot cut through it, and a stud which is fixed to the arm travels in this slot. The arm is not seen in the figure, as it is behind the ratchet wheel. P and Q are two stops at the end of the groove, and Q can be moved up towards P.

The table imparts a definite amount of vibration to the disc F, the whole or any part whereof may be received by the click according as Q is moved close up to P or is separated from it, and thus the amount of feed may be regulated according to the demands of the work.

63. Where the ratchet wheel moves at each vibration of the driver, and not during every alternate movement, an escapement, or something approximating thereto, must be employed. The action now takes place alternately upon opposite sides of the wheel. (Fig. 82.)

Fig. 82.

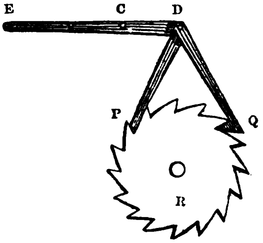


When A *m*, in the common recoil escapement, moves to the left it presses down the point of a tooth; when B *n* moves to the right it presses up the point of another tooth, and each action advances the wheel in the same direction.

It will be observed that this direction is the opposite to that in which the wheel revolves when driving the escapement.

64. The same action results where two clicks are suspended to the vibrating bar, and one of them is furnished with a hook.

Fig. 83.



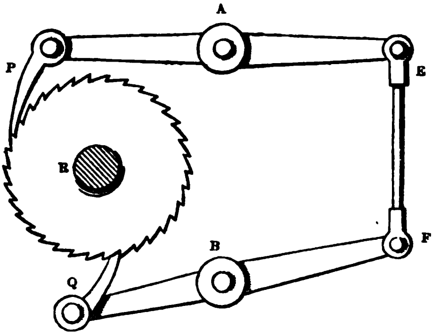
The bar, E C D (Fig. 83.) moves about C as a centre, and the clicks hang at the extremity, D. When P pushes on the wheel, the click Q slips over a tooth; when Q is driving, the click P passes over the point of a tooth, and thus the wheel advances upon each vibration of the moving arm.

The hook may be replaced by a click, as in the annexed example, which has been devised for giving the feed in a planing machine where the cutter acts during each movement of the table.

The levers which carry the clicks are moveable about centres at A and B, and are connected by the link

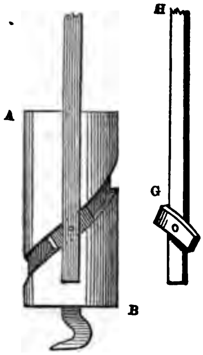
E F. (Fig. 84.) The suspension of two moveable clicks upon a vibrating arm is due to Lagarousse, and follows at once as a modification of the anchor in the last article.

Fig. 84.



65. The converse of the contrivance described in Art. 19. may be used to convert reciprocating into circular motion; that is to say, the bar may be employed to turn the screw barrel instead of the screw driving the bar.

Fig. 85.



Such an arrangement gives rise to a great increase of friction, and is very rarely met with; there is an instance, however, in a drill which is used by dentists, and the movement was at one time proposed by Mr. Whitworth in order to obtain a reversing motion of the cutter in planing machinery.

A rod, H, (Fig. 85.) was provided with a sort of curved tooth, G, which fitted exactly into a groove in the form of a screw thread traced upon the cylinder A B. As the rod moved up and down it reversed the position of the cutter, and enabled the cutting tool to act while the table was reciprocating in either direction.

CHAP. III.

ON THE TEETH OF WHEELS.

66. We propose now to enter into a mathematical investigation of the forms of teeth adapted for the transmission of motion or force in combinations of wheel-work, and we have already stated the general nature of the problem.

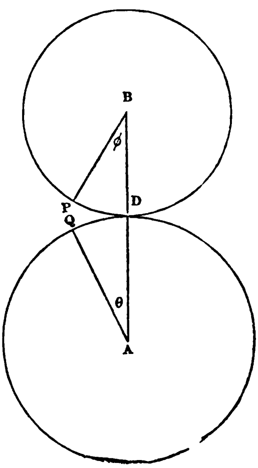
It is required so to shape the teeth or projections upon the edges of two circular discs that the motion resulting from the mutual action of such teeth shall be in no wise distinguishable from the rolling action of two definite circles called the pitch circles of the discs in question.

The various geometrical propositions which enable us to accomplish the solution of the problem will be given in detail, and the practical application of these theorems will also be indicated as briefly as possible.

67. When two circles roll together, their angular velocities are inversely as the radii of the circles.

Let the circles centred at A and B move by rolling through the corresponding angles PBD and QAD. (Fig. 86.)

Fig. 86.



Let $AD = a$, $BD = b$

$QAD = \theta$, $PBD = \phi$

Then $QD = a\,\theta$

$PD = b\,\phi$

But $QD = PD \therefore a\,\theta = b\,\phi$

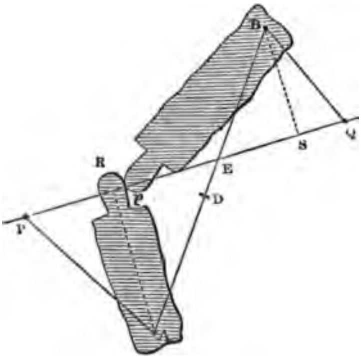
$$\therefore \frac{\theta}{\phi} = \frac{b}{a}$$

$$\text{or } \frac{\angle^r \text{ vel. of A}}{\angle^r \text{ vel. of B}} = \frac{b}{a}$$

which proves the proposition.

68. Let A and B (Fig. 87.) be the centres of motion of two pieces provided with teeth of some determinate form, and conceive that *p* is the point of contact of the teeth in question: draw P *p* Q, a common $\perp^r$ to the touching curves cutting A B in E. Let P and Q be the centres of the circles of curvature of the curves which touch at *p*, and draw A R, B S, $\perp^r$ to B Q. Then, in the first instant of motion, P Q may be regarded as constant, and the angular velocities of the two pieces will be identical with those of A P and B Q.

Fig. 87.



But by Art. (53.)

$$\frac{\angle^r \text{ vel. of } AP}{\angle^r \text{ vel. of } BQ} = \frac{BS}{AR} = \frac{BE}{AE}$$

whence

$$\frac{\angle^r \text{ vel. of piece } A}{\angle^r \text{ vel. of piece } B} = \frac{BE}{AE}$$

Suppose it to be required that the angular velocities of the two pieces shall be the same as those of the pitch circles of radii A D, B D. We must now form the curves so that E shall coincide with D, and shall never leave it during the motion; in other words, the common $\perp^r$ to the surfaces of any two teeth in contact must always pass through the point of contact of the two pitch circles.

If the teeth can be formed so as to satisfy this condition, the problem will be fully solved, and we shall give the solutions which have been devised by the ingenuity of mathematicians.

69. Def. An epicycloid is traced out by a point P in the circumference of one circle, which rolls upon the convex arc of another circle. The curve is represented by the dotted line in Figure 88.

Fig. 88.

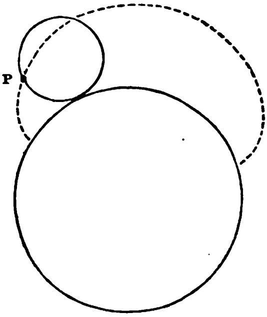
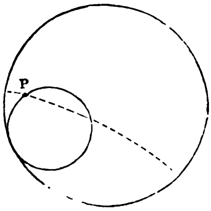


Fig. 89.

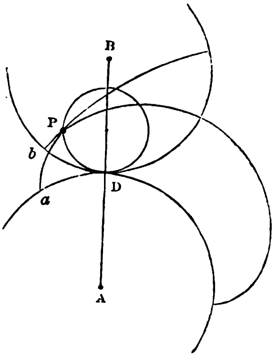


Def. A hypocycloid is traced out by a point P in the circumference of one circle, which rolls upon the concave arc of another circle. The curve is represented by the dotted line in Figure 89.

70. Let now the *same circle* roll upon the outside of the circle A and the inside of the circle B; bring the circles together till the two curves and the circles also touch, as in Figure 90., and it will be found that the common perpendicular at the point of contact passes through D.

The truth of this statement is evident from the consideration that when the curves touch, the describing circle may be taken as ready to generate either the one curve or the other; now the describing circle cannot do this unless it be resting upon both circumferences indifferently, *i. e.* unless it passes through D as well as P, or unless *b* D = *a* D. Hence the condition in Art. **69.** is fulfilled.

Fig. 90.



71. We have now obtained two curves which satisfy the geometrical requirements of the problem, and it remains to put our theory into practice.

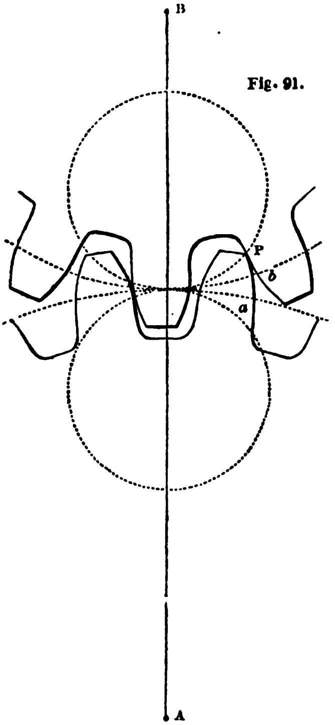


Fig. 91.

The epicycloid and hypocycloid which form the acting surfaces of two teeth must be produced by one and the same describing circle.

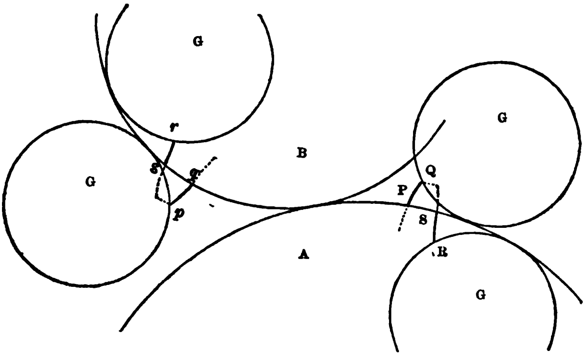
Let A and B be the two pitch circles. (Fig. 91.) Take a circle of any convenient size less than either A or B, and call it G: with G describe an epicycloid upon A and a hypocycloid upon B; let these curves determine the acting surfaces *a* P, *b* P, of two teeth in contact at P; then the tooth *a* P will press against *b* P so that the perpendicular to the surfaces in contact at P shall pass through D, and the relative angular velocities of two pieces centred at A and B, and furnished with these teeth, will be the same as those of the two pitch circles.

As far as we have gone we have described the point of a tooth upon A and the flank of one upon B, and have supposed A to drive B. If the conditions were reversed and B were to drive A, we should again have to obtain from one describing circle the curves suitable for the point of a tooth upon B and the flank of one upon A. This describing circle is not necessarily of the same size as the former one, but it is very advantageous to make it so, and we shall therefore assume that the teeth upon A and B are formed by the *same* describing circle.

72. To complete the form of the teeth so that either A or B may drive, the construction is the following:

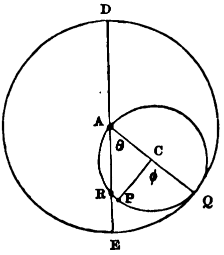
Let the describing circle G (Fig. 92.) trace P Q, S R upon A, and *p q*, *s r* upon B. Then P Q determines the form of all the points of the teeth upon A, and S R that of the flanks, and in the same way *p q* and *s r* together make the point and flank of a tooth upon B.

Fig. 92.



73. There are two particular cases of the above solution yet to be examined.

Fig. 93.



When the diameter of the circle which describes a hypocycloid is taken equal to the radius of the circle within which it rolls, the curve becomes a straight line.

Let C (Fig. 93.) be the centre of the describing circle at any time, and P the corresponding position of the describing point.

Suppose that P begins to move from E, so that the arc P Q may be equal to the arc E Q.

Join C P, A E; let $\text{AEQ} = \theta$, $\text{PCQ} = \phi$

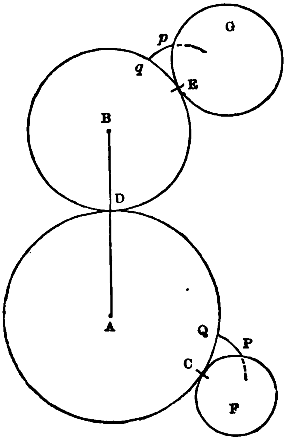
$$\text{Then } \text{PQ} = \text{EQ}$$
$$\text{or } \text{CQ} \times \phi = \text{AE} \times \theta$$
$$\text{But } \text{AE} = 2\,\text{CQ} \therefore \phi = 2\,\theta.$$

Now ϕ cannot be equal to $2\,\theta$ unless P coincides with E in the line A E; in which case the diameter E A D is the path of P.

74. It will be remembered that the hypocycloid determines the flank of the tooth upon either wheel: if, therefore, the radius of the circle describing the hypocycloid be taken in each case to be half that of the corresponding pitch circle, the teeth will have straight, or radial flanks, as they are commonly called.

The method of setting out the teeth is the following:

Fig. 94.



Let A and B be the centres of two pitch circles which touch in the point D. (Fig. 94.)

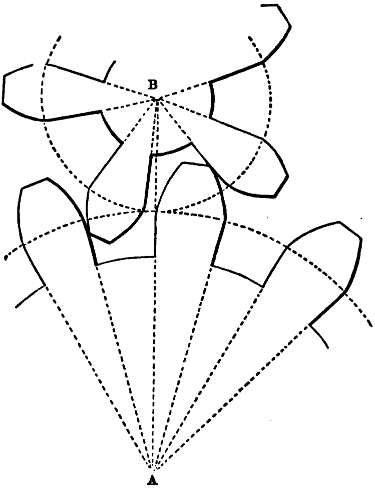
Let a circle, F, whose diameter is equal to B D, roll upon the circle A, and generate the epicycloid Q P; this curve determines the form of the driving surface of the teeth to be placed upon A.

Let a circle, G, whose diameter is equal to A D, roll upon the circle B, and generate the epicycloid $q\,p$; this curve determines the driving surface of the teeth to be placed upon B.

Here of necessity the describing circle is not of the same size when tracing out the points of the teeth upon A and B; but, by reason that the same circle gives the point upon A and the flank upon B, the condition in Art. 69. is still fulfilled.

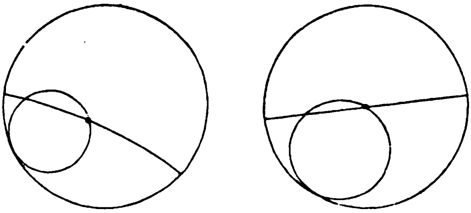
75. In each case the flanks of the teeth are straight lines pointing to the centres of the pitch circles: the form of the teeth is given in the annexed sketch. (Fig. 95.)

Fig. 95.



76. If we trace the changes in form of the hypocycloid, as the describing circle increases in size till it becomes

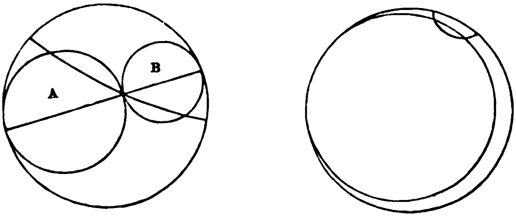
Fig. 96.



equal to that of the circle within which it is supposed to roll, we shall find that the curve gradually opens out into a straight line (Fig. 96.): that it then closes up again, and finally degenerates to a point. (Fig. 97.)

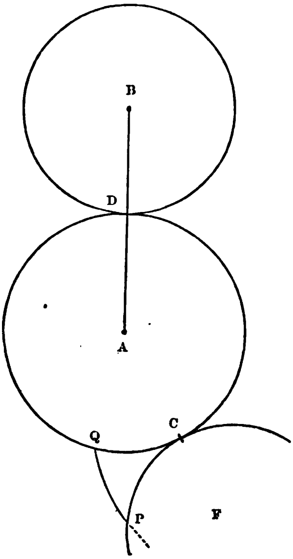
It will also appear that the same hypocycloid is generated by each of the circles A and B, which are so related that the sum of their diameters is equal to the diameter of the circle in which they roll.

Fig. 97.



77. The second particular case of the general solution occurs when the hypocycloid degenerates to a point; then we obtain a wheel with pins in the place of teeth, and derive a form which is extensively used in clockwork.

Fig. 98.



The pin must have some sensible diameter, but we will first suppose it to be a mathematical point.

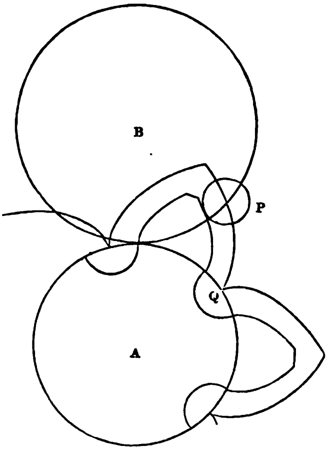
We have just seen that when the hypocycloid becomes a point, the describing circle must be equal to that within which it is supposed to roll. As before, let A and B be the centres of the two pitch circles touching in the point D. (Fig. 98.)

Let a circle, F, equal to B, roll upon the circle A, and generate the epicycloid P Q.

This curve will determine the acting surface of the teeth to be placed upon A: and here again the condition in Art. **69.** is fulfilled.

78. To take into account the size of the pin, we proceed thus:

Fig. 99.



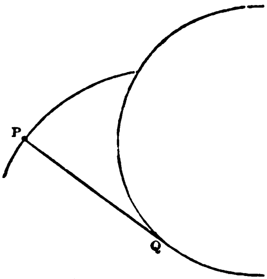
Let Q P (Fig. 99.) represent the acting surface of a tooth which drives before it a point, P.

Make P the centre of a circle equal to the size of the pin: suppose this circle to travel along P Q, having its centre always in the curve; remove as much of the tooth as the circle intercepts, and the remainder will give the form of the working teeth.

We shall presently find that in practice the pins are always placed upon the driven wheel.

79. Another solution is derived from a property of the involute of a circle.

Fig. 100.

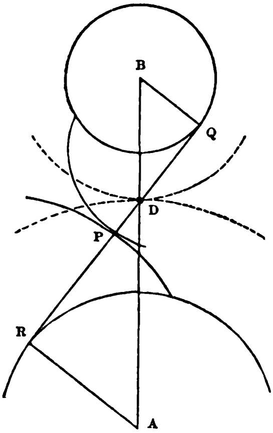


This curve is generated by a describing point, P, at the end of a string P Q, which is kept stretched, and is unwound from the circumference of a circle. (Fig. 100.)

From the mode of generation it is quite evident that the tangent at any point, P, of the curve is $\perp^r$ to P Q, the string in any position, and we proceed to show that this form of curve fulfils in a very simple manner the requirements of Art. **69.**

Let the involutes of two circles of any size be formed, and let them be brought into contact, as in Figure 101.

Fig. 101.

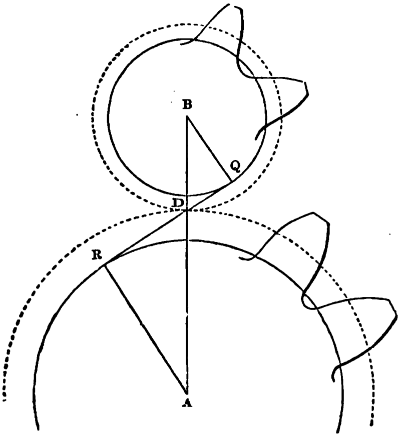


The common tangent at P must be $\perp^r$ to both P Q and P R, or Q P R must be a straight line.

Now Q P R is a common tangent to the two circles, and will therefore cut the line of centres, A B, in a fixed point, D; but Q P R is also a common $\perp^r$ to the surfaces of the two teeth; hence the condition in Art. **69.** is satisfied, and the pieces fitted with involutes of circles will move as if the circle of radius A D, were to roll upon the circle of radius B D.

80. In constructing teeth upon this principle a great latitude is introduced from the circumstance that A D (Fig. 102.) and B D may remain constant while A R and B Q have different values.

Fig. 102.



Having given A D and B D, we must select some angle, R D A, at which to draw the line R Q, and the $\perp^{rs}$ A R, B Q will then give the circles whose involutes form the teeth upon A and B.

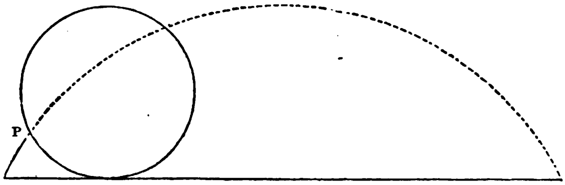
In teeth of this

kind there is no difference in shape between the point and the flank.

81. It remains to apply the above solutions where a pinion drives a rack, or conversely.

In this case one of the pitch circles becomes a straight line, or has an infinite radius, and the curve which is traced out by a point, P, in a circle rolling upon it, is called a cycloid, and is given in Figure 103.

Fig. 103.

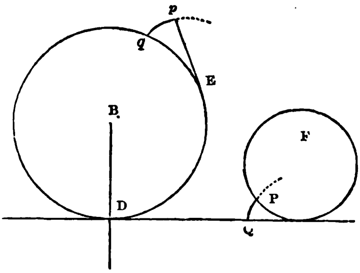


The solution in Art. **71.** is so far modified that the teeth in the rack are formed by cycloids, those in the pinion being the same as before.

The solution in Art. **74.** becomes more altered in character; for here the describing circle which generates the curve of the teeth suitable for the acting surfaces upon the rack is also infinite.

Referring to Art. **74.** the circle F, rolling upon a straight line, generates a cycloid and gives the form of the driving surfaces of the teeth upon the rack: the circle G becomes infinite, and E*p* changes to a straight line. The changes which Fig. 94. undergoes being exhibited in Fig. 104., it is very apparent that the curve *q p* passes into the involute of a circle, or that the driving sur-

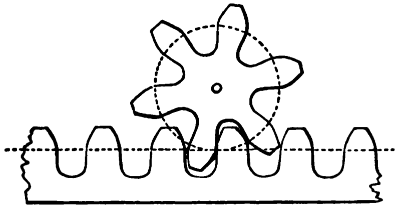
Fig. 104.



faces of the teeth upon the pinion become the involutes of a circle.

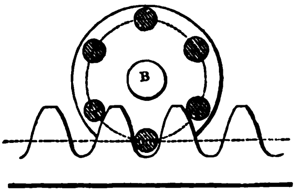
The form of the teeth in the rack and pinion is shown in Figure 105., the flanks in each case being straight lines.

Fig. 105.



82. The solution in Art. **77.** changes as follows:—

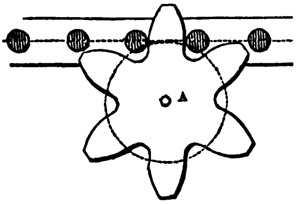
Fig. 106.



Let the circle A become infinite; then the curve, P Q, passes into a cycloid; so that the teeth upon the rack are cycloidal, as in Figure 106.

Here the rack drives the pinion, but it may happen that the pinion drives the rack.

Fig. 107.

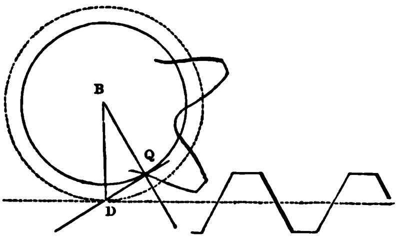


Now the pins are always to be placed upon the follower and not upon the driver, and as a consequence the circle B, in Fig. 98., becomes infinite, C P changes to a straight line, and P Q to the involute of a circle.

The annexed sketch (Fig. 107.) gives the result of the proposition, and shows the pinion driving the rack.

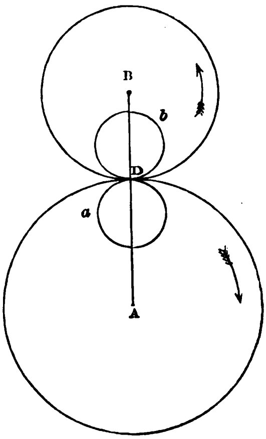
The solution in Art. **79.** changes if the circle A become infinite; in that case the involute of the infinite circle of radius A R is a straight $\perp^r$ to its circumference, or $\perp^r$ Q D. Hence the teeth of the rack are straight lines $\perp^{r}$ to the direction of Q D. The direction of D Q is arbitrary; but, when it has once been assumed, the radius B Q will be determined, and the involute teeth can be formed upon B, the teeth of the rack being straight lines inclined to the pitch line at an angle B D Q. (Fig. 108.)

Fig. 108.



83. There are now sundry general points for consideration. We may inquire, where does the action of two teeth begin, and where does it leave off?

Fig. 109.



Referring to the solution in Art. **71.** we observe that if the motion take place in the direction of the arrows, and the describing circle be placed so as to touch either pitch circle in D, the contact of two teeth commences somewhere in *a* D, travels along the arc *a* D *b*, and ceases somewhere in D *b*.

Since *a* D (Fig. 109.) lies entirely without the pitch circle B, it is clear that the action in *a* D is due solely to the fact that the teeth upon B project beyond the pitch circle B, and similarly that the action in D *b* depends upon the projections or *points* of the teeth upon A.

It is further evident that the greater the number of teeth upon the wheels, the more nearly their action is confined to the neighbourhood of the point D.

By properly adjusting the amount to which the teeth are allowed to project beyond the pitch circles, and also their numbers, we can assign any given proportion between the arcs of contact of the teeth upon either side of the line A D B.

Where the teeth upon B are pins, there is comparatively very little action before the line of centres, and there would be none at all if the pins could be reduced to mere points, as in that case there would be nothing projecting beyond the pitch circle B.

84. It will be proved when we treat of rolling curves that the surface of one tooth must always slide upon that of another in contact with it, except at the moment when the point of contact is passing the line of centres.

This matter should be well understood, the teeth are perpetually rubbing and grinding against each other; we cannot prevent their doing so; our rules only enable us so to shape the acting surfaces that the pitch circles shall roll upon each other.

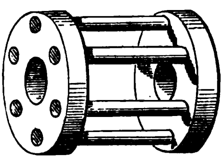
Nothing has been said about the teeth rolling upon each other; it is the pitch circles that roll; the teeth themselves slide and rub during every part of the action which takes place out of the line of centres.

Since, then, the friction of the teeth is unavoidable, it only remains to reduce it as much as possible, which will be effected by keeping the arc of action of two teeth within reasonable limits.

Generally, the friction before a tooth passes the line of centres, is more injurious than that which occurs after the tooth has passed the same line: the difference between drawing a walking-stick along the ground after you and pushing it before you is given by Mr. Denison as an illustration of the difference between the friction before and after the line of centres; but this difference is less appreciable when the arc of contact is not excessive.

Where a wheel drives another furnished with pins instead of teeth, the friction nearly all occurs after the line of centres; hence such pin wheels are very suitable for the pinions in clockwork.

Fig. 110.



There is a very old form of the pin wheel, called a lantern pinion, which is shown in the figure, (Fig. 110.) and which possesses the merit of great strength and durability.

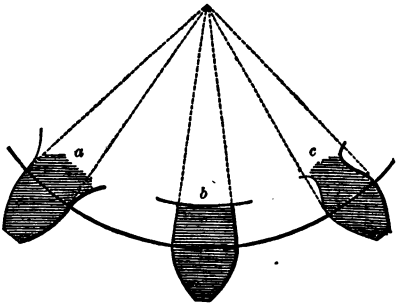
85. Again, since the line D P in Art. **70.** is a $\perp^r$ to the surfaces in contact at P, it follows that the more nearly D P remains $\perp^r$ A D B, the less is the loss of force transmitted between the wheels.

Here we have an additional reason for keeping the arc of contact as close as possible to the point D; there is a sensible loss of power as soon as the line D P differs appreciably from the direction $\perp^r$ to A B.

It is on this account that involute teeth are not used in machinery calculated to transmit great force: the line P D Q in Art. **79.** is always inclined to the line A D B at a sensible angle, and a direct and useless strain upon the bearings of the wheels is the result.

86. As regards the strength of the teeth, we remark that this quality is influenced by the size of the describing circle.

Fig. 111.



If the diameter of the describing circle be less than, equal to, or greater than the radius of the pitch circle, we shall have the flanks as shown in the sectors *a*, *b*, *c* of the figure. (Fig. 111.)

It is evident that a small describing circle makes the teeth strong, and that it would be unwise to have them weaker than they are with radial flanks. The form of involute teeth being somewhat similar to that of a wedge, the teeth of this character are usually abundantly strong.

87. In combinations of wheel-work, the accurate position of the centres must be strictly preserved; all the solutions given above, with one exception, entirely fail if there be any error in centering the wheels; they are totally vitiated if anything arises to deprive them [illegible] their geometrical accuracy. The exception occurs with involute teeth: the position of the centres determines the sum of the radii of the pitch circles, and the wheels will work accurately as long as the teeth are in contact at all.

We see too that teeth with radial flanks are not suitable for a set of change wheels; the describing circles being derived from one pair of pitch circles, cannot be adapted to a different pair.

Where, however, the solution in Art. **71.** is employed, the describing circle may be made the same for any number of pitch circles, and in that case any pair of wheels will work truly together.

88. The teeth upon *bevil wheels* are formed by a method due to Tredgold.

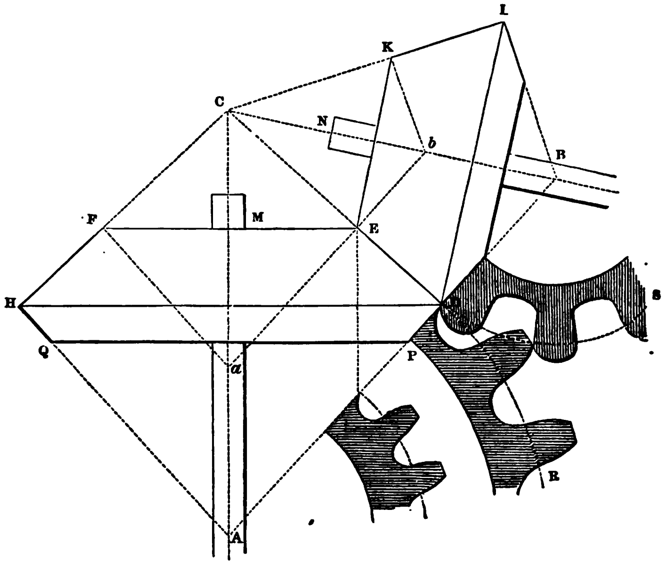
Let FEDH, KEDL, (Fig. 112.) represent the frustra of two right cones, whose axes meet in C, and which are therefore capable of rolling upon each other.

Let it be required to construct teeth upon two bevil wheels which shall move each other just as these cones move by rolling contact.

Draw ADB $\perp^{r}$ DE, meeting the axes of the cones in A and B.

Suppose the conical surfaces H A D, B D L, to have a real existence, and to be flattened out into the circular segments D R, D S; these segments will roll upon each other just as the circular base H D rolls upon the circular base D L.

Fig. 112.



Hence these segments will serve as pitch circles, upon which teeth may be constructed by the previous rules: such teeth may be formed upon a thin strip of metal, and their outline can then be traced upon the surface of the cone terminating in A.

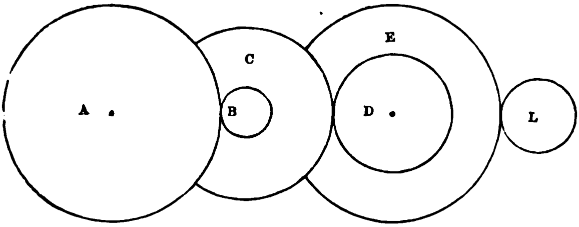
Similarly, if *b* E *a* be drawn $\perp^r$ to E D, the circle of radius A *d* = E *a* will be the pitch circle for the teeth upon the conical surface E *a* F; the teeth will taper from D to E, and the intermediate form will be determined by a straight line moving parallel to itself, and originally passing through D E.

CHAP. IV.

ON THE USE OF WHEELS IN TRAINS.

89. When a train of wheels is employed in mechanism, the usual arrangement is that exhibited in the figure, where two wheels of unequal size are placed upon every axis except the first and last. (Fig. 113.)

Fig. 113.



Let A be the driver, L the extreme follower, and conceive that L makes (e) revolutions while A makes one revolution; we propose to designate (e) as the *value of the train*, so that generally

$$e = \frac{\text{number of revolutions of L in a given time}}{\text{number of revolutions of A in the same time}}.$$

The value of e may be found at once when the numbers of teeth upon the respective wheels are ascertained.

Let A, B, C, D, &c. represent the numbers of teeth upon the respective wheels: the condition of rolling gives

$$\frac{\text{number of revolutions of B in a given time}}{\text{number of revolutions of A in the same time}} = \frac{\text{A}}{\text{B}}$$

and similarly for each pair of wheels:

$$\therefore e = \frac{\text{A}}{\text{B}} \times \frac{\text{C}}{\text{D}} \times \frac{\text{E}}{\text{F}} \times \text{\&c.} \dots \frac{\text{K}}{\text{L}}$$

We may frequently find it very convenient to regard (e) as positive or negative according as A and L revolve in the same or in opposite directions.

We estimate the comparative rotation of wheels in various ways, thus:

Let N, n be the numbers of teeth upon two wheels.
R, r their radii.
P, p their periods of revolution.
X, x the number of revolutions made by each wheel in the same given time.

It is easy to see that

$$\frac{N}{n} = \frac{R}{r} = \frac{P}{p} = \frac{x}{X} = e.$$

Cor. A belt and a pair of pulleys supply a mechanical equivalent for two working wheels: the belt may be open or crossed, and in either case

$$\frac{\text{the number of revolutions of B in a given time}}{\text{the number of revolutions of A in the same time}}$$

$$= \frac{\text{diameter of A}}{\text{diameter of B}}.$$

The crossing of the belt reverses the direction of one of the pulleys.

Ex. Suppose that we have a train of five axes, and that

1. A wheel of 96 drives a pinion of 8.

2. The second axis makes a revolution in 12 seconds, and the third axis in 5 seconds.

3. The third axis drives the fourth by a belt and a pair of pulleys of radii 20 and 6 inches.

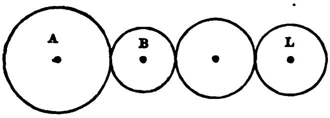
4. The fourth axis goes round twice while the fifth goes round three times.

$$\text{Here } e = \frac{96}{8} \times \frac{12}{5} \times \frac{20}{6} \times \frac{3}{2} = 144$$

or the last axis makes 144 revolutions while the first axis goes round once.

90. When any number of wheels are in gear, as in the figure, they are equivalent to a pair of wheels, viz. the first (A) and the last (L); the intermediate wheels act as carriers merely. (Fig. 114.)

Fig. 114.

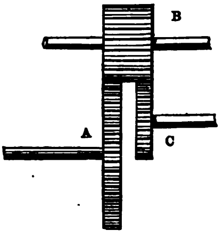


$$\text{Here } e = \frac{A}{B} \times \frac{B}{C} \times \frac{C}{D} \times \ldots \frac{K}{L}$$
$$= \frac{A}{L}.$$

It is very obvious that a wheel and pinion upon the same axis is a combination equivalent to a lever with unequal arms, and modifies the force which may be transmitted through it; a single wheel, however, is equivalent to a lever with equal arms, and produces no modification of the force which may pass through it.

91. If, then, a wheel B (Fig. 115.) be placed between two other wheels A and C, the effect of B will be simply to change the direction in which C revolves: the intermediate wheel will not at all alter the velocity of C, and is therefore called an *idle wheel.*

Fig. 115.



If the axes A and C are too close together to allow space for B, the arrangement in the figure may be adopted where B is a thick wheel gearing into both A and C, and is termed a *Marlborough wheel.*

92. In designing toothed wheels, the following very simple equation connects the diameter of the pitch circle with the number of teeth and their pitch.

Let D be the diameter of the pitch circle in inches.
P the pitch of a tooth in inches.
n the number of teeth upon the wheel.

Then $n.\text{P}$ = circumference of pitch circle $= \pi\,\text{D}$,

where $\pi = 3{\cdot}14159$, or $= \frac{22}{7}$ approximately.

$$\text{Hence } n = \frac{\pi}{\text{P}}\,.\,\text{D}$$

$$\text{or} \quad \text{D} = \frac{\text{P}}{\pi}\,.\,n.$$

In order to save trouble, definite values are assigned to P, such as $\frac{1}{4}$, $\frac{3}{8}$, $\frac{1}{2}$, $\frac{5}{8}$, $\frac{3}{4}$, $\frac{7}{8}$, 1, $1\frac{1}{8}$, $1\frac{1}{4}$, $1\frac{1}{2}$, 2, $2\frac{1}{2}$, &c., and the values of $\frac{\pi}{\text{P}}$, $\frac{\text{P}}{\pi}$ are calculated and registered in a table.

Thus let $\text{P} = 2\frac{1}{2}$ inches, we find in the table that

$$\frac{\pi}{\text{P}} = 1{\cdot}2566 \text{ and } \frac{\text{P}}{\pi} = {\cdot}7958.$$

Suppose a wheel of 88 teeth, and $2\frac{1}{2}$ inch pitch, to be in course of construction, and that we require to know the diameter of the pitch circle.

$$\begin{aligned} \text{D} &= \frac{\text{P}}{\pi}\,.\,n \\ &= {\cdot}7958 \times 88 = 70{\cdot}03 \text{ inches.} \end{aligned}$$

or, again, if the diameter of the pitch circle be 70 inches and the number of teeth of $2\frac{1}{2}$ inch pitch be required,

$$\begin{aligned} n &= \frac{\pi}{\text{P}}\,.\,\text{D} \\ &= 1{\cdot}2566 \times 70 = 87{\cdot}96 \\ &= 88 \text{ very nearly.} \end{aligned}$$

In practice it is more easy to treat of the subdivision of a straight line than of the circumference of a circle, and it is the custom therefore to suppose the diameter of the pitch circle to be divided into as many equal parts as there are teeth upon the wheel, and to designate $\frac{\text{D}}{n}$ as the diametral pitch in contradistinction to P, the circular pitch.

Further, let $\frac{D}{n} = \frac{1}{m}$ where m is a whole number,

$$\text{now } \frac{D}{n} = \frac{P}{\pi} \therefore \frac{1}{m} = \frac{P}{\pi} \text{ or } P = \frac{\pi}{m}$$

The values of m and $\frac{\pi}{m}$ are registered in a table, of which a portion is given, and the circular pitch can be at once found.

Values of m	3	4	5	6	7	8	9	10	12
Values of P	1·047	·785	·628	·524	·449	·393	·349	·314	·262
or approximating	1	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{7}{16}$	$\frac{3}{8}$	$\frac{11}{32}$	$\frac{5}{16}$	$\frac{1}{4}$

Thus let $D = 8$ inches, $n = 80$

$$\therefore \quad \frac{D}{n} = \frac{8}{80} = \frac{1}{10}$$

Hence $P = \cdot 314 = \frac{5}{16}$ inch.

93. A common eight-day clock affords a familiar illustration of the employment of a train of wheels.

Figure 116. represents the disposition of the wheelwork in a clock of this character, and the various wheels are named in the sketch.

The great wheel turns round once in 12 hours, and may have 96 teeth: if then it engage into a pinion of 8 teeth on the axis or arbor of the centre wheel, this pinion will turn 12 times while the great wheel turns once, and is capable of carrying the minute hand.

Suppose the pendulum to swing 60 times in a minute, or to be a seconds pendulum, the scape wheel may have 30 teeth, and will be required to turn once in a minute.

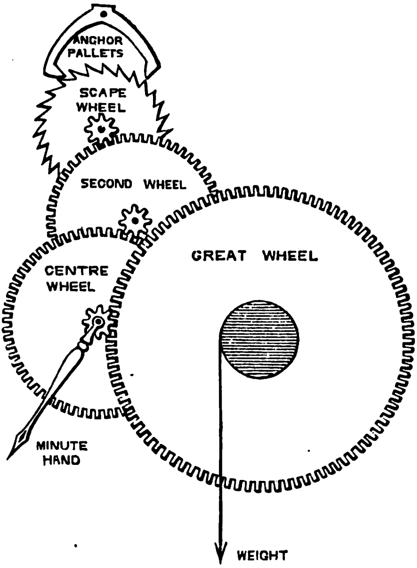
Hence the value of the train from the centre to the scape wheel should be 60; if the pinions on the axes of the second and scape wheels have each 8 teeth, the centre and second wheels may have 64 and 60 teeth: in such a case

$$e = \frac{64 \times 60}{8 \times 8} = 60.$$

In order that the clock may go for 8 days the great wheel must be capable of turning 16 times before the maintaining power is exhausted.

In a watch the balance wheel, which performs the function of a pendulum, makes at least 120 vibrations in a minute, and it is therefore desirable to introduce an additional wheel and pinion into the train.

Fig. 116.

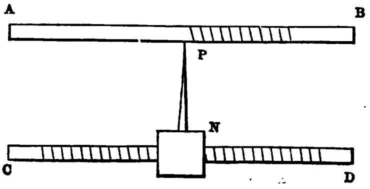


94. The *Screw-cutting Lathe* is constructed upon the following principle:—

A B and C D (Fig. 117.) are two parallel axes; a screw thread of a certain pitch is formed upon C D, and the slide rest, which carries the cutting tool, derives its motion from a nut placed upon C D.

In the figure we suppose the nut N to carry a pointer, P, which may trace a screw thread upon A B.

Fig. 117.



Upon each revolution of C D the nut

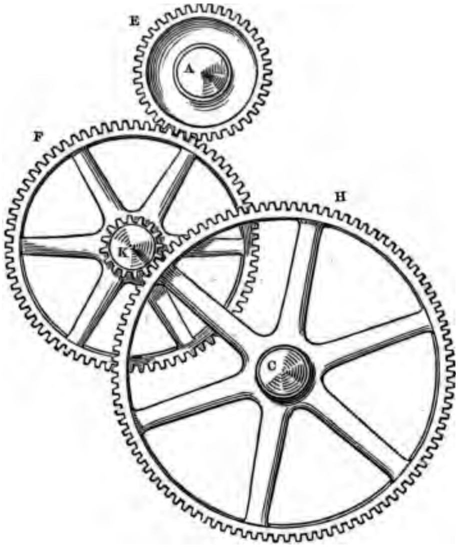
advances through a space equal to the pitch of the screw; if A B also revolve at the same rate as C D, and in the same direction, the point P will describe upon A B a screw thread exactly similar to that upon C D; if A B revolve more or less rapidly than C D, the pitch of the screw upon A B will be less or greater than that upon C D.

Generally if A B make (m) revolutions for (n) revolutions of C D,

$$\frac{\text{pitch of screw on A B}}{\text{pitch of screw on C D}} = \frac{n}{m}.$$

The axes A B, C D are connected by a train of wheels, as in the diagram annexed. (Fig. 118.)

Fig. 118.



Let E, F, K, H represent the numbers of the teeth upon the wheels so distinguished;

$$\text{Then } (e) \text{ the value of the train} = \frac{\text{E} \times \text{K}}{\text{F} \times \text{H}}$$

$$\therefore \frac{\text{pitch of screw upon A B}}{\text{pitch of screw upon C D}} = \frac{\text{E} \times \text{K}}{\text{F} \times \text{H}}$$

Ex. Let the pitch of the screw upon C D be $\frac{1}{2}$ an inch, and let it be required to cut a screw of $\frac{1}{13}$ inch pitch upon A B, or a screw with 13 threads to the inch.

$$\text{Here } e = \frac{2}{13}$$

which is satisfied in the following manner:—

$$\frac{E \times K}{F \times H} = \frac{90 \times 20}{130 \times 90}$$

A series of change wheels is furnished with a lathe, and a table indicates the wheels required for cutting a screw of any given number of threads to the inch. The screw upon C D having 2 threads in an inch, the numbers of teeth to be assigned to E, F, H, K are given in the table of which a specimen is subjoined.

No. of Threads per Inch.	E	F	K	H
12	90	90	20	120
$12\frac{3}{4}$	60	85	20	90
13	90	90	20	130
$13\frac{1}{2}$	60	90	20	90
$13\frac{3}{4}$	80	100	20	110
14	90	90	20	140

The guiding screw being right-handed, the above arrangement is suitable for cutting right-handed screws.

To cut a left-handed screw it is essential that A B and C D shall revolve in opposite directions.

Now A B revolves with the mandril of the lathe, and therefore the direction of the rotation of C D must be reversed; this is effected by interposing an idle wheel between H and K, which reverses the motion of the guide screw C D, and makes the nut travel in the reverse direction. There is a double slot upon the arm which carries K, in order to allow of the adjustment of this idle wheel.

95. The following contrivance (Figs. 119, 120.) is very largely employed in machinery for cutting metals. It enables the mechanic to change from a higher to a lower velocity, and gives another simple example of the use of wheels in trains.

Fig. 119.

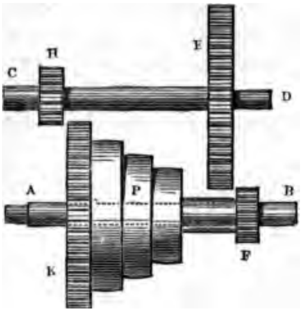
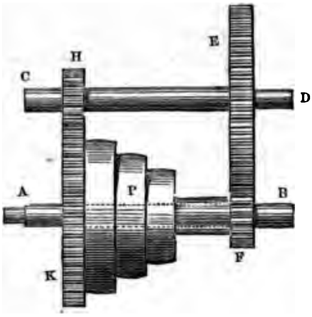


Fig. 120.



A B is the driving shaft upon which the cone pulley, P, rides loosely; F is a wheel attached to P and moving with it; K is a wheel keyed upon the shaft A B; C D is a second axis fitted with wheels, E and H, and capable of being shifted into the position shown in Figure 119.

At ordinary speeds the wheels E and H are out of gear, and P is fastened to K by means of a moveable pin. (Fig. 119.)

The motion then goes from P to K, and so to the driving shaft, A B.

When a slow speed is required, the axis C D is moved into the position in Fig. 120., and the pin connecting P and K is removed; the wheel F turns with P, drives the wheel E, and so the motion passes through H to K, and thus to the driving shaft. The speed of A B is therefore reduced by the multiplier $\frac{F \times H}{E \times K}$, where E, F, H, K represent the numbers of teeth upon these wheels respectively.

96. The problem of connecting two axes by a suitable intermediate train of wheels may in some cases prove extremely troublesome, and may demand a considerable amount of arithmetical ingenuity.

The value of *e* being assigned as a fraction, the only thing to be done is to resolve the numerator and denominator into their prime factors, and then to compose the best train which may suggest itself.

If any of the factors appear unmanageably large we may approximate to the value of *e* by continued fractions, and seek other factors which present less difficulty. If the value of *e* be an integer, it must still be split up into factors, and be further multiplied and divided by the numbers of teeth in each pinion.

Thus, suppose that two axes are to be connected whereof one revolves in 24 hours, and the other in 365 days, 5 hours, 48 minutes, 48 seconds, as in Mr. Pearson's Orrery.

Since 24 hours = 86400 seconds,
and 365 days, 5 hrs. 48 min. 48 sec. = 31556928 seconds,

$$\therefore e = \frac{31556928}{86400}$$

$$= \frac{164359}{450}$$

$$= \frac{269 \times 47 \times 13}{10 \times 9 \times 5}.$$

Here 269 is an inconveniently large number, and 5 is certainly too small.

The wheel of 269 teeth cannot be got rid of without altering the entire ratio, but the pinions of 9 and 5 teeth may be changed into others of 18 and 10 teeth.

$$\text{Thus we have } e = \frac{269 \times 26 \times 94}{10 \times 10 \times 18}.$$

Those who have approximated to *e* by an algebraical process have derived the fraction

$$\frac{94963}{260} = \frac{11 \times 89 \times 97}{4 \times 5 \times 13}$$

$$= \frac{44 \times 89 \times 97}{8 \times 10 \times 13}$$

which avoids the high number 269, and corresponds to a period of 365 days, 5 hours, 48 min., 55·38 sec.

If e be an integer, as 720 for example,

$$e = 10 \times 9 \times 8$$
$$= \frac{80 \times 72 \times 64}{8 \times 8 \times 8},$$

which gives a probable solution for the train.

It is also a matter of inquiry to ascertain the smallest number of intermediate wheels which will suffice to transmit any required motion.

The smallest number of teeth which are to be allowed upon a pinion must be given, as well as the largest number to be allowed upon any wheel.

Suppose that no pinion is to have less than 6 teeth and no wheel more than 60, and let us trace the values of e.

With two axes $e = \frac{60}{6} = 10.$

If the numerator be diminished, or the denominator be increased, the resulting value of e is lessened, or in other words, 10 is the greatest possible value of e when two axes are employed.

With three axes the greatest value of e is $\frac{60 \times 60}{6 \times 6}$ or 100, and with four axes it is 1000, and so on.

Let e have some value between 10 and 100, we now find that three axes will suffice, and that each wheel must have less than 60 teeth in order to reduce e from 100 to 60.

$$\text{Thus } e = \frac{48}{6} \times \frac{45}{6} = 60.$$

Again, let $e = \frac{365}{3} = 121\frac{2}{3}$, and suppose 180 and 12 to be the limiting numbers of teeth upon a wheel and pinion respectively, in the train which is about to be composed.

$$\text{Then } \frac{180}{12} = 15$$

$$\text{and } \frac{180}{12} \times \frac{180}{12} = 15 \times 15 = 225.$$

Now $121\frac{2}{3}$ is $\angle$ 225, and therefore three axes will suffice as in the train represented by

$$e = \frac{180}{18} \times \frac{146}{12}$$

Generally, let p be the least number of teeth upon a pinion, w the greatest number upon a wheel, x the number of fractions in e: then the greatest possible value of e will be given by the equation

$$e = \left(\frac{w}{p}\right)^x$$

$$\text{whence } \log e = x\,(\log w - \log p)$$

$$\therefore\ x = \frac{\log e}{\log w - \log p}$$

x will probably be a fraction, in which case the next integer greater than $x + 1$ will represent the required number of axes.

Ex. Let $e = \frac{365}{3}$, $w = 180$, $p = 12$

$$\therefore\ \frac{w}{p} = 15 \quad \therefore\ x = \frac{\log 365 - \log 3}{\log 15}$$

$$= 1 + \text{a fraction.}$$

Now the integer next greater than $x + 1$ is 3, or 3 axes will be required as shown above.

We observe that it is not necessary to find the actual value of x, but simply to ascertain the integer next greater than it.

97. Next let a wheel of A teeth drive one of B teeth where A is 7 B, and let $\frac{\text{A}}{\text{B}} = \frac{a}{b}$ in lowest terms.

1. Let it be required to bring the same teeth into contact *as often* as possible.

Since this contact occurs after b revolutions of A or a revolutions of B, we shall effect our object by making a and b as small as possible, that is, by providing that A and B shall have a large common measure.

2. Let it be required to bring the same teeth into contact *as seldom* as possible.

Here we must try and prevent A and B from having any common measure at all.

Ex. Let $A = 72$, $B = 24$

$$\text{then } \frac{a}{b} = \frac{72}{24} = \frac{3}{1}$$

or the same pair of teeth will be in contact after three revolutions of B, or one revolution of A.

Next let $A = 73$, $B = 24$, then $\frac{a}{b} = 3$ very nearly, and the relative angular velocity of A and B is scarcely distinguishable from what it was originally.

But now $\frac{A}{B} = \frac{73}{24}$ and is already a fraction in its lowest terms; there will therefore be a contact of the same pair of teeth only after 73 revolutions of B, or 24 revolutions of A.

The insertion of a tooth in this manner was an old contrivance of millwrights to prevent the same pair of teeth from meeting too often, and was supposed to ensure greater regularity in the wear of the wheels; the tooth inserted was called a *hunting cog.*

The clockmakers, on the contrary, appear to have adopted the opposite principle.

Finally, we would remind the reader that everything which we have said here about wheels in trains is true, whatever be the directions of their axes; we only care to know the relative sizes of the pitch circles, and the directions in which they turn; any part of the train may be composed of *bevil wheels* without affecting our results.

CHAP. V.

AGGREGATE MOTION.

98. We have seen that every case of the curvilinear motion of a point is of a compound character, resulting from the superposition of two or more rectilinear motions.

It often happens in machinery that some revolving wheel or moving piece becomes the recipient of more than one independent motion, and that such different movements are concentrated upon it at the same instant of time.

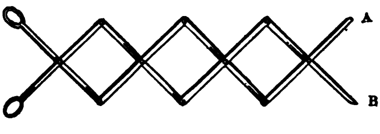
The motion is then of a compound or *aggregate* character, and we propose to classify under the head of Aggregate Motion a large variety of useful contrivances.

We may commence with two or three very simple examples.

The well-known frame called *Lazy Tongs* is a contrivance depending upon aggregate motion. (Fig. 121.)

The rapid advance of the ends A and B is due to the fact that these points are the recipients of the sum of the resolved parts of the circular motion which takes place at each angle.

Fig. 121.



99. Hunter's differential screw is another instance.

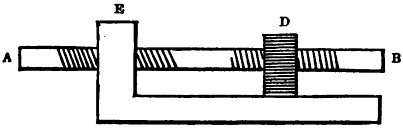
A B represents an axis upon which are formed two screw threads of different degrees of inclination, but of the same character.

E is a fixed nut, and D slides along the frame.

Let P, Q, represent the pitches of the screws at E and D;

upon turning A B once the nut D is carried forward through a space P, and is brought back again through a space Q; it therefore advances through the difference of these intervals.

Fig. 122.



If one screw thread were right-handed and the other left-handed, the nut would travel through a space, P + Q, upon each revolution. (Fig. 122.)

The usual form of the contrivance is given in Figure 123., where one screw is a hollow pipe whose interior surface acts as a nut for the second screw. The result is precisely the same as before.

Fig. 123.

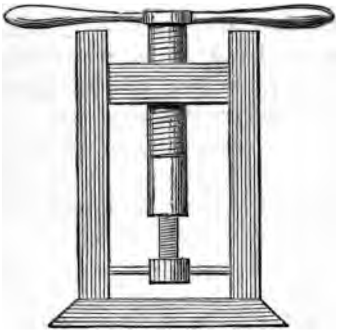
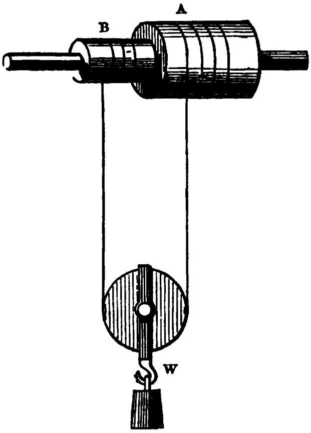


Fig. 124.



100. In the *Chinese Windlass* (Fig. 124.) a rope is coiled in opposite directions round two axles, A and B, of unequal size; the rope is consequently unwound from one axle while it is being wound up by the action of the other.

Let R, r be the radii of the axles, then W moves through $2\pi(R - r)$ upon each revolution of the axles.

The length of string required for each revolution is more-ever 2π (R + r) and is so large that the contrivance is practically of little value.

101. The subject of ***Epicyclic trains*** will now occupy our attention, and we shall discuss some of the most useful applications of that peculiar arrangement of wheelwork which is technically so designated.

An epicyclic train differs from an ordinary train in this particular: the axes of the wheels are not fixed in space, but are attached to a rotating frame or bar, in such a manner that the whole train of wheels can derive motion from the revolutions of the bar.

There are certain fundamental forms which consist of trains of two or three wheels; the first wheel of the train is usually concentric to the revolving arm, and the last wheel may be so likewise.

These elementary forms are exhibited in the annexed diagrams, and the peculiarities which result from compounding any independent motion with that which arises from the rotation of the arm will demand some careful and attentive study.

Fig. 125.

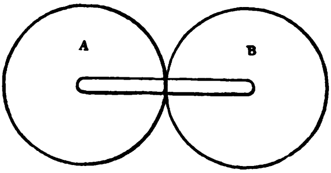
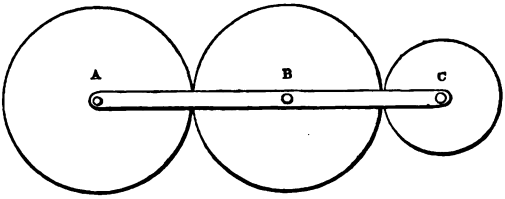


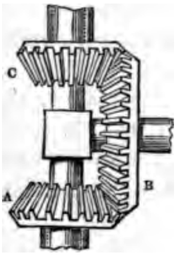
Fig. 126.



In Figures 125. and 126. the wheels A, B, or the wheels A, B, and C, are attached to a bar which is capable of revolving about the centre of the wheel A.

In Figure 127. we have a combination of three bevil wheels, whereof the axes of A and C are identical and fixed in space, and the wheel B is carried round upon an arm which supports it.

Fig. 127.



It should be understood that any number of intermediate wheels may exist between the first and last wheels of the train, and that the wheels in the train may derive the whole of their motion from the arm, or they may receive one portion from the arm and the remainder from an independent source.

102. Let the arm make a revolutions
The first wheel A make m revolutions
The last wheel C make n revolutions
} during the same period of time,

and let e (Art. 89.) be the *value* of the train. Then the first wheel makes $(m - a)$ revolutions relatively to the arm, and the last wheel makes $(n - a)$ revolutions relatively to the same arm; whence it follows that $e = \frac{n - a}{m - a}$.

There are three cases to consider:—

1. Let A be fixed or $m = 0$

$$\therefore\ e = \frac{n - a}{-a} = -\frac{n}{a} + 1$$

$$n = a\,(1 - e) \text{ and } a = \frac{n}{1 - e}$$

2. Let C be fixed or $n = 0$

$$\therefore\ e = \frac{-a}{m - a}$$

$$\therefore m = a\left(1 - \frac{1}{e}\right) \text{ and } a = \frac{m\,e}{1 - e}$$

3. Let neither of these wheels be fixed.

Then $m\,e - a\,e = n\,a$

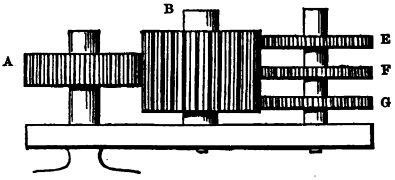
$$\therefore\ a = \frac{m\,e - n}{e - 1} = \frac{m\,e}{e - 1} + \frac{n}{1 - e}$$

that is to say, the number of revolutions of the arm is the aggregate of the separate revolutions which it would have received in the two former cases.

103. *Ferguson's Paradox* is obtained by placing three wheels upon the axis which usually carries C, and making these wheels very nearly equal to each other and very nearly equal to A.

Thus let A (Fig. 128.) have 20 teeth, and the numbers of teeth upon E, F, G be 21, 20, 19 respectively.

Fig. 128.



The number of teeth upon B is immaterial.

For the wheel E we have $e = \frac{20}{21}$ which is less than unity.

$$\therefore \frac{n}{a} = 1 - \frac{20}{21} = \frac{1}{21} \text{ and is positive.}$$

2. For the wheel F; $e = \frac{20}{20} = 1 \therefore \frac{n}{a} = 0$

3. For the wheel G; $e = \frac{20}{19}$

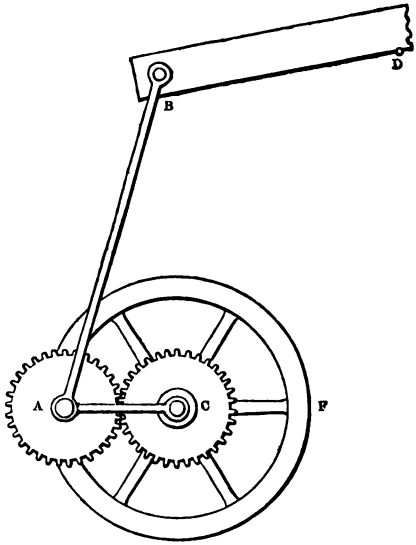
$$\therefore \frac{n}{a} = 1 - \frac{20}{19} = -\frac{1}{19} \text{ and is negative.}$$

So that when the arm is made to revolve, the wheel E turns slowly in the same direction as the arm, F remains at rest, and G moves slowly in the reverse direction.

104. The *Sun and Planet Wheels* were invented by Watt, and were used to convert the reciprocating motion of the working beam of an engine into the circular motion of the fly wheel.

The wheel A (Fig. 129.) is supposed to be fixed to the arm A C, and at the same time to derive motion from the working beam B D, by its attachment to the connecting rod A B.

Fig. 129.



F is the fly wheel of the engine, and C is a spur wheel centred upon the same axis as F, and turning with it.

Here A is fixed to the arm or $m = 0$.

Also A and C turn in opposite directions $\therefore$ e is negative, and the formula in Art. **102.** gives $n = a + e\,a$.

If A and C be equal, or $e = 1$ the equation becomes $n = 2\,a$ and the fly wheel makes two revolutions for each one of the crank arm.

105. An illustration may now be taken from the cotton mills of Lancashire.

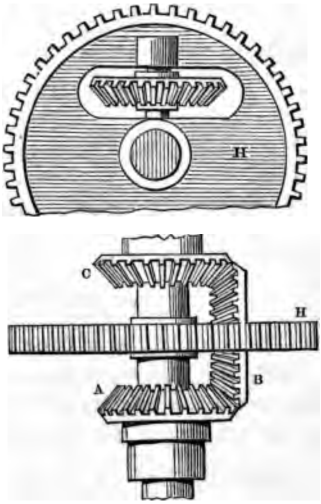
During the process of the manufacture of cotton yarn or thread, it is essential to wind the partially twisted fibre upon bobbins, and at the same time to protect it from any undue strain.

The fibre is delivered to the bobbins at a uniform rate, whereas the bobbins get larger as they fill with the material or *roving*, and hence the winding machinery must be so contrived that the rate of revolution of the bobbin shall slowly decrease upon the completion of each layer of the fibre.

In the year 1826 Mr. H. Houldsworth patented an invention which solves the problem of the *bobbin motion* in the most complete and satisfactory manner.

In the last case of Art. **101.** we have supposed the wheel B to be carried by an arm which is capable of revolution round the axis A C; the best way, however, of suspending B is to attach it to the face of a wheel H, as in Figure 130.

Fig. 130.



Let this be done, and let A be connected with the driving shaft of the engine, so that the rotation of A shall necessarily be constant.

If now some independent motion be imparted to the wheel H, the result may be calculated from the formula.

Here A, B, C are equal in size.

$$\therefore \quad e = -1$$
$$\therefore n - a = a - m$$
$$\therefore n + m = 2a$$

which gives the analytical relation between the angular velocities of A, B, C.

As soon as we examine this formula, we shall comprehend that the velocity of C may be reduced by altering the velocity of H.

1. For let $a = m$, or let A and H turn at the same rate,

$$\text{Then} \quad n + m = 2\,a = 2\,m$$

$$\therefore\ n = m, \text{ or C has exactly the same motion as A.}$$

2. Let $a = \frac{3\,m}{4}$ *i. e.* let H make 3 revolutions while A makes 4.

$$\therefore \quad n + m = 2 \times \frac{3\,m}{4} = \frac{3\,m}{2}$$

$$\therefore\ n = \frac{m}{2} \text{ or C moves half as fast as A.}$$

3. Let $a = \frac{m}{2}$ in which case H makes one revolution for two revolutions of A.

$$\therefore \quad n + m = 2 \times \frac{m}{2} = m$$

$$\therefore \quad n = 0, \text{ or C stops altogether.}$$

106. We have taken extreme cases, from which it appears that when the velocity of the arm is made less than that of A, the velocity of C is reduced in a twofold degree.

Generally, let $a = m - \frac{m}{x}$

$$\begin{aligned}\therefore\ n &= 2\,a - m \\ &= 2m - \frac{2\,m}{x} - m \\ &= m - \frac{2\,m}{x}\end{aligned}$$

or the diminution of n is twice that of a.

It now becomes easy to obtain any required reduction in the velocity of C: a reduction in the velocity of H must first be effected by shifting a driving strap along a conical pulley, and the velocity of C will be reduced exactly twice as much as that of H.

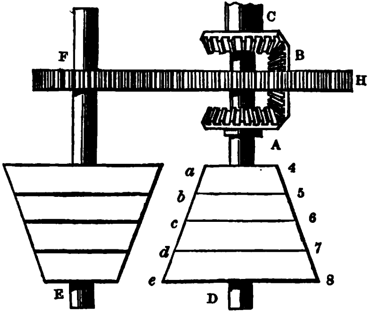
Mr. Houldsworth's invention consists, therefore, in imparting to the wheel C two independent motions which travel *by different routes*, and which, after combination in the manner just investigated, are capable of producing the desired *bobbin motion.*

107. In order to fix our ideas let us calculate the motion in the following example: —

Suppose A, B, C (Fig. 131.) to be three equal wheels, and that A is fixed to a shaft A D, which carries a conical pulley provided with steps at *a*, *b*, *c*, *d*, *e*, where the diameters are 4, 5, 6, 7, 8.

E F is another shaft carrying a second conical pulley which is the counterpart of the first, and terminating in a wheel F whose diameter is half that of H.

Fig. 131.



A crossed strap connects the two cones, and the axis A D is made to revolve with a uniform velocity.

It is required to deduce the motion of C when the strap is shifted along the conical pulley.

1. Let the strap be placed at *a*, the velocity of H will be $\frac{1}{4}$ that of A D.

$$\therefore a = \frac{m}{4} \text{ and } n = 2 \times \frac{m}{4} - m = -\frac{m}{2}$$

or C moves in the opposite direction to A, and with half its velocity.

2. Let the strap be at *b*, the vel. of H will be $\frac{5}{14}$ that of

A D $\left(\text{here } e = \frac{5}{7} \times \frac{1}{2} = \frac{5}{14} \text{ according to Art. 89.}\right)$

$$\text{or } a = \frac{5\,m}{14} \text{ and } n = 2\,a - m = \frac{5\,m}{7} - m$$

$$= -\frac{2\,m}{7}$$

or C still moves in the opposite direction to A, but less rapidly in the ratio of 2 to 7.

3. Place the strap at *c*,

$$\text{then } a = \frac{m}{2} \therefore n = 2 \times \frac{m}{2} - m = 0$$

or C stops altogether.

4. Place the strap at *d* $\therefore a = \frac{7\,m}{5} \times \frac{1}{2} = \frac{7\,m}{10}$

$$\text{whence } n = 2\,a - m = \frac{7\,m}{5} - m = \frac{2\,m}{5}$$

i. e. C and A move in the same direction with velocities in the ratio of 2 to 5.

5. Finally adjust the strap at *e*, and the velocity of H will be the same as that of A D.

Here $a = m$ and $n = 2\,m - m = m$,

or the motion of C is precisely the same as that of A.

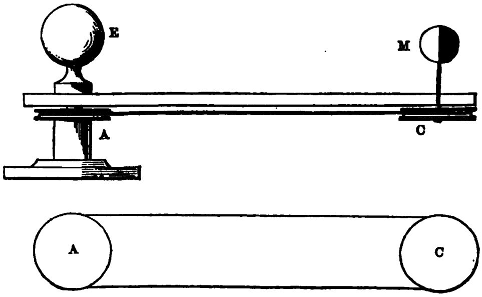
108. Numerous models intended to illustrate simple astronomical problems connected with the motion of the heavenly bodies are formed upon the principle which is under discussion.

The subjoined arrangement exhibits mechanically the phases of the moon.

Here wheelwork is dispensed with; A and C are simple discs of wood connected by a gutta-percha band, as in the diagram. The band may be crossed or otherwise, according as the discs are required to turn in opposite or the same direction.

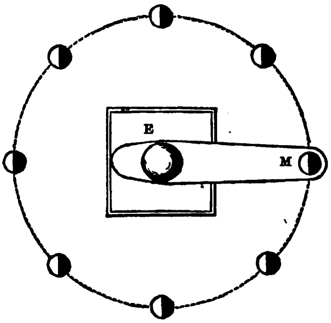
E is the earth (Fig. 132.); a white ball M, fixed rigidly

Fig. 132.



to the arm, represents the moon; a hemispherical black cap fits upon M, and is connected with the disc C, so as to move with it. If the cap is to represent the dark portion of the moon's surface, it must not rotate as the arm revolves, and this is clearly the case of the wheel F in Ferguson's Paradox; consequently A must be equal to C, and the band which connects A and C must not be crossed.

Fig. 133.



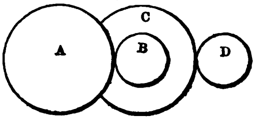
As the arm revolves the disc C remains fixed in direction and the hemispherical cap takes the positions indicated in the diagram. (Fig. 133.)

109. Epicyclic trains may be employed to produce a very slow motion upon the following principle:—

Let A, B, C, D (Fig. 134.) represent the numbers of teeth in a train of wheels in gear arranged as in the figure.

If A = D, and B = C, then A and D will rotate with the same velocity in the same direction, but if the equality between (A, D) and (B, C) be slightly disturbed, we shall produce a small change in the *value* of the train.

Fig. 134.



Suppose A to be ∠ D, as for example, A = 31, D = 32
and B to be ∠ C or B = 125, C = 129.

Then *e*, the *value* of the train, will be

$$= \frac{31 \times 129}{125 \times 32} = \frac{3999}{4000}$$

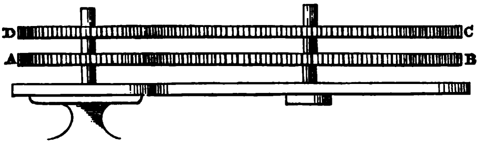
Also the more nearly the equality is maintained between (A, D) and (B, C) the more nearly will the angular velocities of A and D be the same, or the more nearly will *e* be equal to unity.

Thus if B $= $ D $= 100$, A $= 101$, C $= 99$

$$\text{we have } e = \frac{101 \times 99}{100 \times 100} = \frac{9999}{10000}$$

Let us now arrange A, B, C, D, in an epicyclic train, then the turning of the arm will set all the wheels in motion, and we shall have D and A moving relatively to each other just as before, that is to say, D will turn very slowly over A at rest. (Fig. 135.)

Fig. 135.



Taking the formula $\frac{n}{a} = 1 - e$, and substituting for e the values given above,

we have in the first example $\frac{n}{a} = \frac{1}{4000}$

and in the second example $\frac{n}{a} = \frac{1}{10000}$

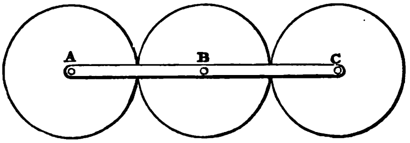
Hence the arm will make 4000 or 10000 revolutions respectively while the wheel D turns round once.

110. This last example leads us to compare the movement of any wheel in an epicyclic train with that in another train where the axes are fixed in space.

Take a very simple case, such as that of three equal wheels, A, B, C. (Fig. 136.)

If the arm be fixed, and A makes one turn, the wheel C will also turn once in the same direction. But if the arm revolve round A fixed, the wheel C will apparently run round just as it did upon the last supposition, and yet at the end of

Fig. 136.



a revolution of the arm, C will be found not to have turned at all.

The explanation is that the fixed train gives the absolute motion of C due to its connection with A, whereas the epicyclic train exhibits the *relative* motion of C with regard to A.

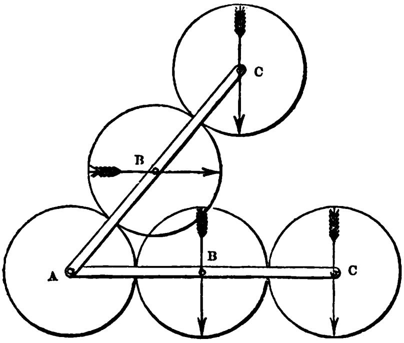
The same thing is true with respect to B, which acquires the rotation of the arm as well as the rotation due to A, and makes two revolutions while the arm goes round once.

In a train with fixed axes the wheels A and B turn in opposite directions, and their relative motion is the sum of their apparent motions; so therefore we conclude that B exhibits in an epicyclic train the rotation which it would have had *relatively* to A in a fixed train.

This fact was made use of by Watt, in the construction of the sun and planet wheels, described in Art. **104**.

In the adjoined figure (Fig. 137.) we suppose the arm to revolve through an ∠ of 45°; it will be seen that B has

Fig. 137.



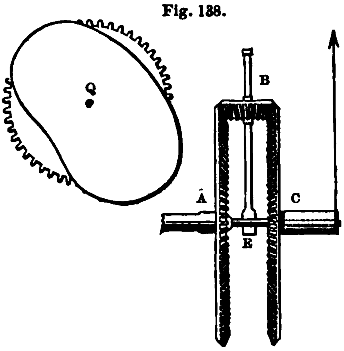
moved through a right angle while C has not turned at all.

111. Equation clocks afford a further illustration of the use of epicyclic trains.

In these nearly obsolete pieces of mechanism the minute hand points to true solar time, and its motion therefore consists of the equable motion of the ordinary minute hand plus or minus the *equation* or difference between true and mean solar time.

In these clocks (Fig. 138.) the hand pointing to true solar time is fixed to the bevil wheel.

Fig. 138.



The wheel A moves as the minute hand of an ordinary clock; the intermediate wheel B is fixed to a swinging arm E B, as in case 3, and the position of C will be in advance of that of A when E B is moved a little in the same direction, and behind that of A when E B is moved in the opposite direction.

Thus as C goes round during each hour of the day, the hand attached to it may be a few minutes before or behind another showing mean time, and deriving its motion at once from A.

The required motion of E B is obtained from a cam plate, Q, curved as in the Figure, and attached to a wheel which revolves once in a year.

112. The *Parallel Motion* used in steam-engines was the invention of the illustrious James Watt, and was announced in the specification of the patent which he obtained in the year 1784.

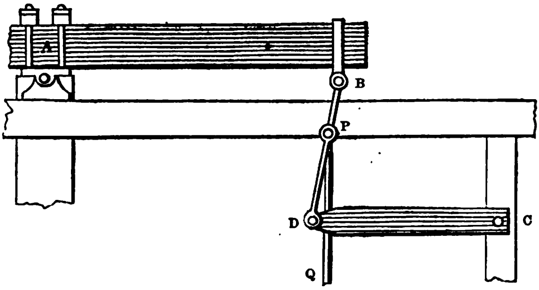
We quote the description of this invention in Watt's own words.

"My second new improvement on the steam-engines consists in methods of directing the piston rods, the pump rods, and other parts of these engines, so as to move in perpendicular or other straight or right lines, without using the great chains and arches commonly fixed to the working beams of the engines for that purpose, and so as to enable

the engine to act on the working beams or great levers both by pushing and by drawing, or both, in the ascent and descent of their pistons. I execute this on three principles.
* * * * The third principle on which I derive a perpendicular or right lined motion from a circular or angular motion, consists in forming certain combinations of levers moving upon centres, wherein the deviations from straight lines of the moving end of some of these levers are compensated by similar deviations, but in opposite directions, of one end of other levers."

The annexed sketch in Figure 139 is copied from the original drawing.

Fig. 139.

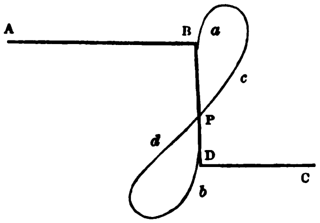


A B is the working beam of the engine, P Q the piston rod or pump rod attached at P to the rod B D, which connects A B and another bar, C D, moveable about a centre at C.

"When the working beam is put in motion the point B describes an arc on the centre A, and the point D describes an arc on the centre C, and the convexities of these arcs, lying in opposite directions, compensate for each other's variation from a straight line, so that the joint P, at the top of the piston rod, or pump rod, which lies between these convexities, ascends and descends in a perpendicular or straight line."

113. This invention being clearly an example of aggregate motion, we proceed now to discuss it in a careful manner, and to examine its peculiar features.

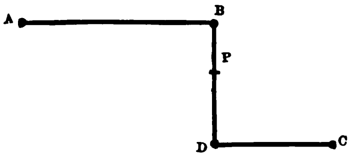
Fig. 140.



In Figure 140. A B and C D are supposed to represent two rods moveable about centres at A and C, and connected by a link, B D. If B D be moved into every position which it can assume, the path of any point P in B D will be a sort of figure of eight, of which two portions, *a b*, *c d*, are nearly straight lines.

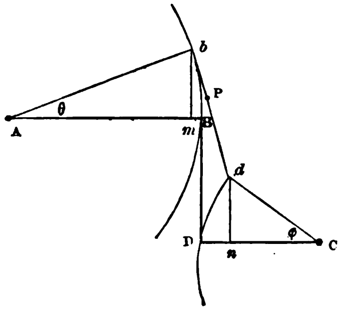
114. At the beginning of the motion let the rods (Fig. 141.) be so placed that the $\angle^{s}$ at B and D shall be right angles.

Fig. 141



We shall now endeavour to discover that point in B D which most nearly describes a straight line, and in doing so, we first remark that B D begins to shift in the direction of its length, and therefore that the straight line in question coincides with B D.

Fig. 142.



Suppose the rods to be moved into the position A *b d* C as shown in Figure 142. Draw *b m*, *d n* $\perp^{r}$ to A B and C D respectively, and let P be the required point; also let

$$\mathrm{AB}=a \quad b\mathrm{P}=x \quad \mathrm{BA}b=\theta$$
$$\mathrm{CD}=b \quad \mathrm{P}d=y \quad \mathrm{DC}d=\phi$$

We shall further suppose that the motion of A B and

C D is restricted within narrow limits, and shall deal approximately with our equations, by putting

$$\sin\frac{\theta}{2}=\frac{\theta}{2} \quad \text{and} \sin\frac{\phi}{2}=\frac{\phi}{2}$$

$$\text{then } \frac{x}{y}=\frac{b\,\text{P}}{d\,\text{P}}=\frac{\text{B}\,m}{\text{D}\,n}=\frac{a\,(1-\cos\theta)}{b\,(1-\cos\phi)}$$

$$=\frac{a\;2\sin^2\frac{\theta}{2}}{b\;2\sin^2\frac{\phi}{2}}$$

$$=\frac{a\,\theta^2}{b\,\phi^2}\text{ nearly.}$$

But the link only turns through a very small angle, which may be considered to be nothing as a first approximation, in which case the vertical motion of B is equal to that of D,

$$\text{or} \quad b\,m = d\,n$$

$$a\sin\theta = b\sin\phi$$

$$\text{whence } a\,\theta = b\,\phi \text{ nearly.}$$

$$\therefore \frac{x}{y}=\frac{a}{b}\times\frac{b^2}{a^2}=\frac{b}{a}$$

$$\text{or } \frac{b\,\text{P}}{\text{P}\,d}=\frac{\text{C D}}{\text{A B}}$$

i.e. the point P divides B D into two parts which are inversely as the length of the nearest radius rods.

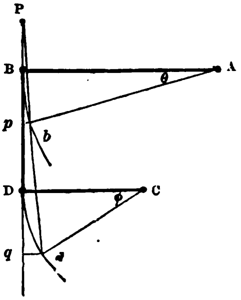
115. If the radius rods be arranged on the same side of the link, the point P will lie in D B produced. (Fig. 143.)

Suppose the rods to be moved into the position A b d C, and draw $b\,p$, $d\,q$ $\perp^{\text{r}}$ B D and B D produced respectively.

$$\text{Then } \frac{b\,\text{P}}{d\,\text{P}}=\frac{b\,p}{d\,q}=\frac{a\,(1-\cos\theta)}{b\,(1-\cos\phi)}$$

$$=\frac{a\,\theta^2}{b\,\phi^2}$$

Fig. 143.



Also $a\,\theta = b\,\phi$ as before,

$$\therefore \frac{b\,\mathrm{P}}{d\,\mathrm{P}} = \frac{a}{b} \times \frac{b^2}{a^2} = \frac{b}{a}$$

a proportion which determines the position of P.

116. We have supposed that $\sin\theta = \theta$ and $\sin\phi = \phi$ in the previous investigation; it is worth a little enquiry to ascertain how far we may proceed upon this supposition without introducing any sensible error.

Referring to the tables, we find that the circular measures of angles of 1, 5, 10, 15, 20 degrees, and the natural sines of the same angles are the following: —

Angle.	Circular Meas.	Natural Sine.	Difference.
1°	·0174533	·0174524	·0000009
5°	·0872665	·0871557	·0000108
10°	·1745329	·1736482	·0008847
15°	·2617994	·2588190	·0029804
20°	·3490659	·3420201	·0070458

In practice the beam of an engine seldom describes an angle of more than 20° on each side of the horizontal line, and within that limit the error consequent upon our assumption would not be considerable.

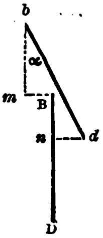
The investigation just concluded gives the point P, which most nearly describes a straight line, and we may now enquire how much P really deviates from the rectilinear path at any given period of its motion.

117. In an engine of the usual construction A B is equal to C D, and we shall simplify our results by making this supposition.

Let B D move into the position *b d*, and turn through an angle, α; it is very apparent that within the limits to which the rods move in practice, α will be much less than θ or ϕ, so that we may regard α as a close approximation to the actual values of sin α even when we do not adopt the same supposition with regard to θ and ϕ.

The object of the investigation will be to determine ϕ in terms of θ, and we shall see that the deviation sought for depends upon the difference of the cosines of ϕ and θ.

Fig. 144.



As before, observing that $b = a$ we have (Fig. 144.)

$$\text{B}\,m = a\,(1 - \cos\theta)$$
$$m\,b = a\sin\theta$$
$$d\,n = a\,(1 - \cos\phi)$$
$$\text{D}\,n = a\sin\phi$$

Let $\text{B D} = l$, then $l + m\,b = l\cos\alpha + \text{D}\,n$

or $l + a\sin\theta = l\cos\alpha + a\sin\phi$

$$\therefore a\sin\phi = a\sin\theta + l\,(1 - \cos\alpha) \quad (1)$$

Now α being the angle through which B D is twisted, and being moreover very small, we shall have

$$l\,\alpha = \text{B}\,m + d\,n \text{ very nearly}$$
$$= a\,(1-\cos\theta) + a\,(1-\cos\phi)$$
$$= 2\,a\,(1-\cos\theta) \text{ since } \phi \text{ is nearly equal to } \theta$$
$$\therefore \quad \alpha = \frac{2\,a}{l}(1-\cos\theta) \text{ very approximately.}$$

By substituting in equation (1) we can calculate ϕ with considerable accuracy, and then the deviation of P from the vertical line will $= d\,n - \text{B}\,m$

$$= \frac{a}{2}(\cos\theta - \cos\phi)$$

and can therefore be ascertained.

Ex. Let $\theta = 20$, and assume $a = b = 50$ inches, $l=30$ in.

$$\therefore \quad \alpha = \frac{2\,a}{l}(\cdot 0603074)$$
$$= \frac{10}{3}(\cdot 0603074)$$
$$= \cdot 2010247$$

or α represents the angle of 11° 31′.

Substituting in equation (1) we have

$$\begin{aligned}\sin\phi &= \sin 20 + \frac{3}{5}(1 - \cos 11^\circ\, 31') \\ &= \cdot 3420201 + \frac{3}{5}(\cdot 0201333) \\ &= \cdot 3541001 \\ \therefore \phi &= 20^\circ\, 44' \text{ nearly.}\end{aligned}$$

The deviation of P from the vertical

$$\begin{aligned}&= \frac{50}{2}(\cos 20^\circ - \cos 20^\circ\, 44') \\ &= 25\,(\cdot 0044544) \\ &= \tfrac{1}{10}\text{th of an inch approximately.}\end{aligned}$$

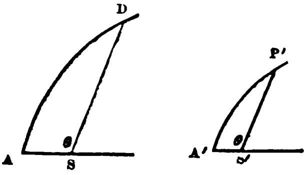
It may be shown that this amount of deviation is again capable of reduction if we cause the centres of motion, A and C, to approach each other by shifting them horizontally through small spaces.

118. The point P, whose motion has been examined, is usually found at the end of the air-pump rod. We have now to obtain a second point, also describing a straight line, and suitable for attachment to the end of the piston rod.

A species of jointed parallelogram enables us to effect this object upon the following principle:—

Two curves are said to be similar when two radii can be drawn from two points similarly situated, such that if any two other radii be drawn equally inclined to the former, the four are proportional.

Fig. 145.



Ex. Thus all parabolas are similar curves, and all ellipses with the same eccentricity are similar curves.

Let A, A′, (Fig. 145.) be the vertices, S, S′, the foci of two parabolas.

Then S A, S′ A′ are two lines drawn from two points similarly situated.

Let S P, S′ P′ be radii inclined at the same ∠ θ to S A, S′ A′ respectively.

$$\text{Then } SP = \frac{2\,SA}{1+\cos\theta}$$

$$S'P' = \frac{2\,S'A'}{1+\cos\theta}$$

$$\therefore \quad \frac{SP}{S'P'} = \frac{SA}{S'A'}$$

whence the curves are similar.

Again if S be the focus, C the centre of an ellipse,

$$\text{the eccentricity} = \frac{CS}{CA}$$

Suppose the curves to represent ellipses of eccentricity e and e' respectively.

$$\therefore \quad SP = \frac{SA\,(1+e)}{1+e\cos\theta}$$

$$S'P' = \frac{S'A'\,(1+e')}{1+e'\cos\theta}$$

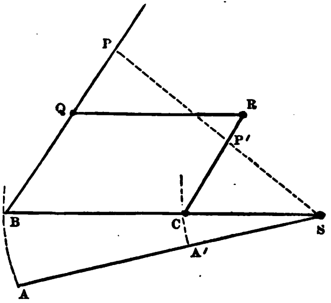
$$\text{Let } e = e'$$

$$\text{Then } \frac{SP}{S'P'} = \frac{SA}{S'A'} \text{ or the curves are similar.}$$

119. The subjoined contrivance enables us to draw a curve similar to any given curve.

Let B Q R C represent a jointed parallelogram of which the sides B C, B Q are produced to convenient lengths; make any point S in B C S a centre of motion, and it will be found that by turning the frame round S, and at the same time opening or closing in some degree the angle Q B C, a point P in B Q produced may be made to follow the path of any given curve upon the plane of the paper.

Fig. 146.



Join S P, cutting C R in P′, then the point P′ will trace out a curve similar to the path of P. For suppose B and C (Fig. 146.) to have originally coincided with A and A′, so that S A′ A is a fixed line upon the paper.

$$\text{Then } \frac{\text{SP}}{\text{SP}'} = \frac{\text{SB}}{\text{SC}}$$

$$\text{But SC} = \text{SA}', \text{SB} = \text{SA}$$

$$\therefore \quad \frac{\text{SP}}{\text{SP}'} = \frac{\text{SA}}{\text{SA}'}$$

and the $\angle$ A S P = the $\angle$ A′ S P′

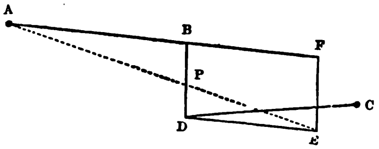
∴ the points P and P′ trace out similar curves.

If, therefore, P′ describe a straight line, the point P will do the same.

This arrangement, which is technically known as a *Pantograph*, enables us to complete the problem of the parallel motion.

120. To the system, A B C D, (Fig. 147.) is superadded the parallelogram B F D E; A B F being the working beam of the engine.

Fig. 147.



The point E lies in A P produced, and is the point of attachment of the end of the piston rod.

$$\text{Let AB} = a, \text{CD} = b, \text{BF} = x$$

$$\text{Then } \frac{x}{a} = \frac{\text{DP}}{\text{PB}} \text{ by similar } \Delta^s \text{ ABP, DPE}$$

$$\text{But } \frac{\text{DP}}{\text{PB}} = \frac{\text{AB}}{\text{CD}} = \frac{a}{b}$$

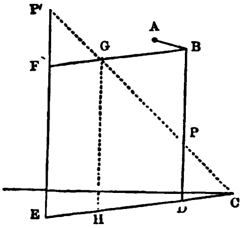
$$\therefore \frac{x}{a} = \frac{a}{b} \text{ or } x = \frac{a^2}{b}$$

which equation determines the proportion between A B, C D, and B F, in order that the second point sought for may lie at the vertex E of the given parallelogram.

121. Where a beam engine is used in a steam vessel the beam must be kept as low down as possible, and the motion is altered as in the figure, but it is precisely the same in principle.

Let $\mathrm{AB} = a$, $\mathrm{CD} = b$, $\mathrm{DE} = c$, $\mathrm{BD} = l$, $\mathrm{FP'} = x$, where $\mathrm{P'}$ is the point whose path is similar to that of P, and C D E is the beam of the engine. Draw $\mathrm{GH} \parallel$ to F E,

Fig. 148.



$$\text{Then } \frac{\mathrm{HD}}{\mathrm{CD}} = \frac{\mathrm{GB}}{\mathrm{CD}} = \frac{\mathrm{BP}}{\mathrm{PB}}$$

$$\text{But } \frac{\mathrm{BP}}{\mathrm{PD}} = \frac{\mathrm{CD}}{\mathrm{AB}}$$

$$= \frac{a}{b}$$

$$\therefore \frac{\mathrm{HD}}{b} = \frac{b}{a} \text{ or } \mathrm{HD} = \frac{b^2}{a}$$

$$\text{Also } \frac{\mathrm{FP'}}{\mathrm{FE}} = \frac{\mathrm{FP'}}{\mathrm{HG}} = \frac{\mathrm{EH}}{\mathrm{CH}}$$

$$\therefore \frac{x}{l} = \frac{\mathrm{DE} - \mathrm{HD}}{\mathrm{HD} + \mathrm{CD}} = \frac{c - \dfrac{b^2}{a}}{\dfrac{b^2}{a} + b} = \frac{ac - b^2}{b\,(a + b)}$$

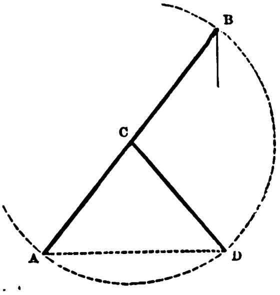
$$\therefore x = \frac{l}{b} \cdot \frac{ac - b^2}{a + b} \text{ which gives } x.$$

122. Another form of parallel motion was devised for marine engines before the principle of direct action was so generally adopted. It was fitted to the engines of the "Gorgon" by Mr. Seaward, and has since been applied to small stationary engines.

It is a modification of a simple geometrical fact.

Let the rod A B (Fig. 149.) be bisected in C, and jointed at that point to another rod, C D, which is equal in length to A C. Suppose the point D to be fixed, and that the end, A, of the rod A B

Fig. 149.



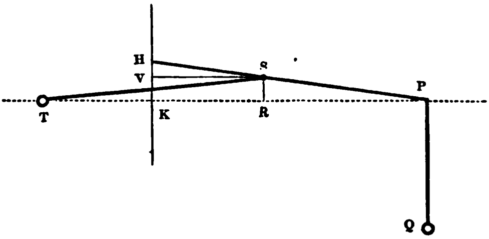
describes a straight line pointing to D, then B will also describe a straight line pointing to D.

This is evident from the fact that C is always in the centre of a circle passing through A, D, and B, and of which A C B is the diameter.

123. The system of rods T S, H P, P Q, exhibits the parallel motion of the "Gorgon" engines.

T and Q (Fig. 150.) are the centres of motion, and H is the point which most nearly describes a straight line H K; draw S R, S V $\perp^r$ to T P and H K respectively.

Fig. 150.



Let T S $= a$, S H $= b$, S P $= c$, S T R $= \theta$, S P R $= \phi$.

Then T R $= a \cos \theta = a\left(1 - 2\sin^2\frac{\theta}{2}\right) = a\left(1 - \frac{\theta^2}{2}\right)$ nearly,

$$\text{S V} = b \cos \phi = b\left(1 - \frac{\phi^2}{2}\right) \text{ nearly,}$$

$$\therefore \text{T K} = a - b - \frac{a\,\theta^2}{2} + \frac{b\,\phi^2}{2}$$

But the point H describes the straight line H K.

$$\therefore \text{T K} = a - b$$

$$\therefore \frac{b\,\phi^2}{2} - \frac{a\,\theta^2}{2} = 0 \text{ or } a\,\theta^2 = b\,\phi^2$$

$$\text{But } \frac{a}{c} = \frac{\sin \phi}{\sin \theta} = \frac{\phi}{\theta} \text{ nearly,}$$

$$\therefore \frac{a}{b} = \frac{a^2}{c^2}$$

$$\therefore c^2 = ab,$$

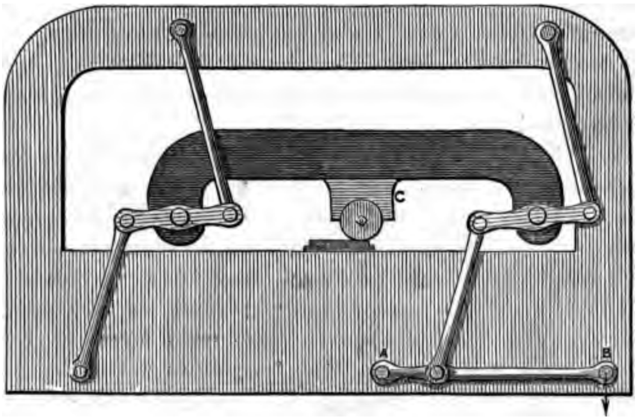
or TS : SP :: SP : SH, a condition which must be fulfilled by the rods giving the parallel motion.

124. A ***Parallel Motion*** may be useful in miscellaneous machinery.

In the old process of multiplying engraved steel plates at the Bank of England, it was necessary to roll a hardened steel roller upon a flat plate with a very heavy pressure. The difficulty of maintaining this pressure during the motion of the roller upon the plate was overcome by the aid of the parallel motion indicated in the figure. (Fig. 151.)

The system of jointed bars allowed the heavy frame C to traverse laterally, while the necessary pressure was obtained by a pull upon the end of the lever A B.

Fig. 151.



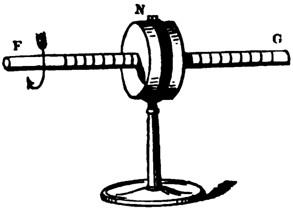
125. A further illustration of aggregate motion occurs in machinery for drilling and boring.

In a drilling machine the spindle which carries the cutting tool revolves rapidly, and at the same time advances slowly in the direction of its length.

The movement is obtained upon a very obvious principle.

Suppose a nut, N (Fig. 152.) to be placed upon a screw bolt, F G, and to be so held in a ring or collar that it can rotate freely without being capable of any other motion.

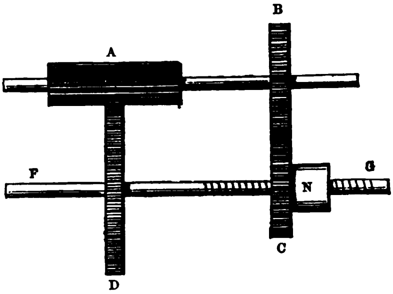
Fig. 152.



If the nut be fixed, and F G be turned in the direction of the arrow, it is clear that the bolt must advance through the nut; if, again, the screw be prevented from turning, and the nut be made to rotate in the same direction as before, the bolt will come back again. And, finally, if by any contrivance different amounts of rotation be impressed at the same time upon the nut and the screw, the bolt will receive the two longitudinal movements simultaneously, and the aggregate motion will be the sum or difference of its component parts.

126. Suppose the wheels D and C to be attached to the bolt and nut respectively, and to be driven by the pinions A and B, and let A, B, C, D represent the numbers of teeth upon the respective wheels.

Fig. 153.



If (a) be the number of rotations made by A or B during (m) rotations of C and (n) of D,

$$\text{we have } \frac{m}{a} = \frac{\mathrm{B}}{\mathrm{C}} \qquad \frac{n}{a} = \frac{\mathrm{A}}{\mathrm{D}}$$

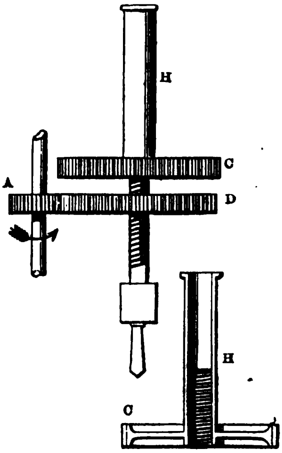
Therefore (a) rotations of A will cause a travel of the bolt F G through $(m - n) \times$ pitch of the screw

$$= a\left(\frac{\mathrm{B}}{\mathrm{C}} - \frac{\mathrm{A}}{\mathrm{D}}\right) \times \text{pitch of the screw.}$$

127. A Drilling Machine by Mr. Bodmer, of Manchester, affords a good example of the principle under discussion.

The drill spindle (Fig. 154.) has a screw thread traced upon it; a groove is cut longitudinally along the spindle, and a projection upon the interior of the boss of the wheel D fits accurately into the groove.

Fig. 154.



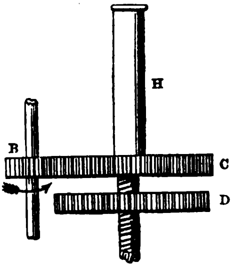
Thus the spindle can traverse through the wheel D, although the spindle and wheel must turn together.

A nut, H, in the form of a pipe, and having a wheel, C, at the bottom of it, receives the spindle; this wheel and pipe are shown separately in section.

If a pinion, A, turning in the direction shown by the arrow, engage the wheel D, it will screw the spindle rapidly through the nut H, and bring it down towards the work.

Suppose a second pinion B (Fig. 155.) turning in the same direction as A to act upon C, it will move the nut instead of the screw, and the drill spindle will rise rapidly.

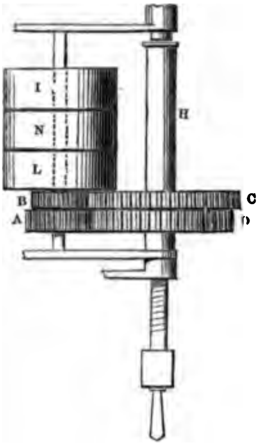
Fig. 155.



Thus far we have provided for bringing the spindle down to its work, and for raising it up again; it remains to apply the principle of aggregate motion, to cause the drill spindle to become the recipient of these two movements in a nearly equal degree, and thereby to ensure the slow descent accompanied by a rapid rotation, which is required in process of drilling.

The result of the combination is shown in the next diagram, where the wheels A and B are moved together; the wheel A tends to depress the spindle, the wheel B tends to raise it, and the spindle descends by the difference of these two motions having further the motion of rotation given by the wheel A. (Fig. 156.)

Fig. 156.

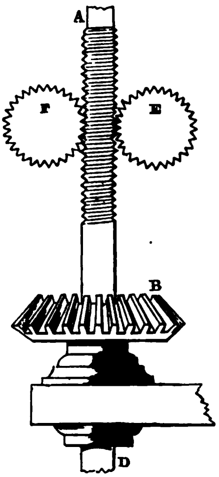


The motions of A and B are obtained from the driving pulleys I, N, and L.

I is an idle pulley; N drives A and L drives B. When the strap is on N the drill descends to the work; when the strap is on L it ascends from the work, and when the strap is partly on N and partly on L the drilling proceeds.

128. Mr. Whitworth's Friction Drilling Machine is an elegant application of the principle under discussion.

Fig. 157.



A D (Fig. 157.) is the drill spindle, driven in the usual manner by the bevil wheel B.

E and F are two worm wheels embracing the screwed portion of the spindle upon opposite sides.

If E and F be prevented from turning, they will form a nut through which the spindle will screw itself rapidly.

If E and F be allowed to turn quite freely, the drill spindle will set them in motion, and the nut will be virtually eliminated. The drill spindle may then be regarded as the recipient of two equal and opposite motions; it is depressed by screwing through a nut, it is elevated by the turning of the wheels.

If the rotation of the wheels be in any degree checked by the application of friction, the equality is destroyed, and the drill spindle descends to a corresponding extent.

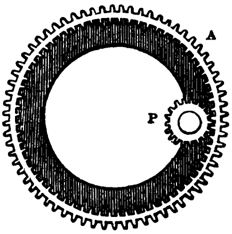
A friction brake, regulated by a screw, restrains the motion of E and F, and gives a perfect command over the working of the machine.

When B is at rest the worm wheels act upon the spindle as a pinion does upon a rack, and the drill can be rapidly brought down to the work.

129. A *Boring Machine* would be employed to give an accurately cylindrical form to the interior surface of a steam cylinder.

In the annexed example the boring cutters are attached to a frame which rides upon a massive cast-iron shaft or boring bar, and rotates with it; this frame is further the recipient of a slow longitudinal movement given by a screw.

Fig. 158.

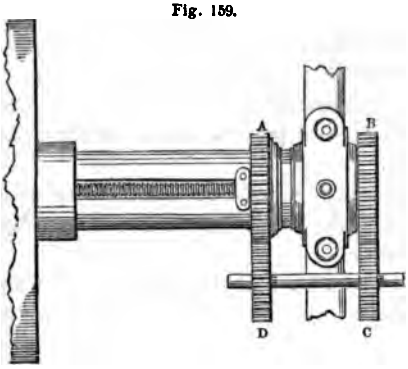


An annular wheel, A, (Fig. 158.), shaped as in the figure, rides loose upon the bar, and drives a pinion, P, at the end of the feeding screw which advances the cutters, the boring bar being recessed in order to receive the screw.

It is quite apparent that as long as the rotation of the wheel A is identical with that of the boring bar, the pinion P will not turn at all; and further that a slow motion will be impressed upon P, if the rotation of A is made to lag a little behind that of the bar.

A wheel, B, is keyed to the bar, and a small shaft at the side carries the wheels C and D, and thus motion is imparted to A, and thence to the feeding screw. Let the numbers of teeth on B, C, D be 64, 36, 35, and let the wheel H have 64 teeth, both upon the outside and the inside of its circumference, the pitch of the screw being $\frac{1}{2}$ an inch, and the number of teeth upon the pinion being 16. (Fig. 159.)

Fig. 159.



$$\text{Here } e = \frac{B \times D}{C \times A} = \frac{64 \times 35}{36 \times 64} = \frac{35}{36}$$

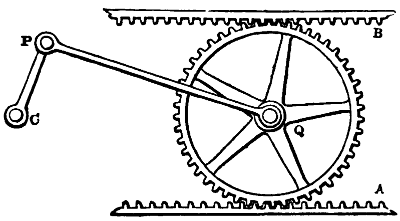
i. e. A loses $\frac{1}{36}$th of a revolution for every complete rotation of the boring bar. At the same time the pinion P moves through $\frac{1}{36} \times \frac{64}{16}$ or $\frac{1}{9}$ of a revolution, and the cutter advances through $\frac{1}{9} \times \frac{1}{2}$ an inch or through $\frac{1}{18}$th of an inch.

130. In some printing machines the table is driven by a crank and connecting rod, and the length of its path may be doubled upon the principle under discussion.

A wheel rolling upon a plane is a case of aggregate motion; the centre of the wheel moves parallel to the plane, the wheel itself revolves about its centre, and these two simple motions give the aggregate result of rolling.

Let a wheel, Q, (Fig. 160.) be attached to the end of the connecting rod P Q, so that it can turn freely on its centre, Q. Let the wheel revolve between two racks, A and B, whereof A is fixed to the framework of the machine, and B is attached to the table.

Fig. 160.



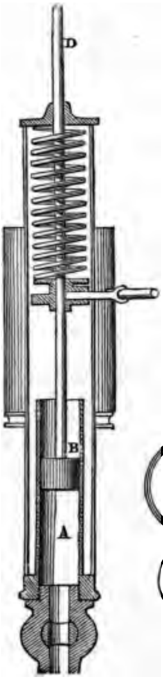
The rack B receives the motion of Q in its twofold character, and moves through exactly twice the space that it would describe if connected simply with the point Q.

The size of the wheel makes no difference in the result.

131. *Watt's Indicator* is an instrument used to ascertain the actual horse power of a working steam-engine. The principle upon which it is constructed is the following:—

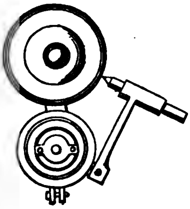
A pencil oscillates through the space of a few inches in a straight line, with a velocity which always bears a fixed ratio to that of the piston, and at the same time is the subject of a second motion at right angles to the former, which occurs whenever the pressure of the steam upon one and the same side of the piston becomes greater or less than that of the atmosphere.

Fig. 161.



Under the influence of these independent motions the aggregate path of the pencil will be a curve which is capable of interpretation, and which affords a wonderful insight into the working of the engine.

The indicator consists of a small cylinder A, fitted with a steam-tight piston, B; the piston rod, B D, is attached to a spiral steel spring, which is capable of extension and compression within definite limits, and is enclosed in the upper part of a tube which carries the cylinder A.

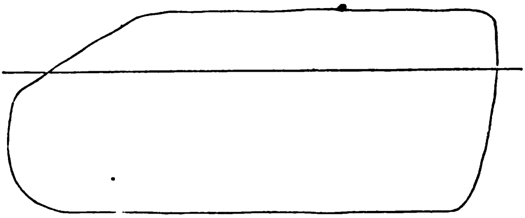


The pencil is attached to a point in the rod B D, (Fig. 161.) and traces the indicator diagram upon a piece of paper wrapped round a second cylinder by the side of the first.

The cylinder, A, is freely open to the atmosphere at the top, and a stop-cock admits the steam when required. The indicator is usually fixed upon the cover at one end of the steam cylinder of the engine. When the stop-cock is opened and the lower side of B is in free communication with the interior of the cylinder, the pressure of the steam will be usually greater or less than that of the atmosphere; if it be greater, B will rise against the pressure of the spring, and if it be less, the pressure of the atmosphere upon the upper surface of B will overcome the spring and cause the pencil to descend.

At the same time the cylinder which carries the paper is made to turn with a motion derived at once from that of the piston in the engine, but much less in degree, and thus a curve somewhat similar to that shown in figure 162 will be described.

Fig 162.



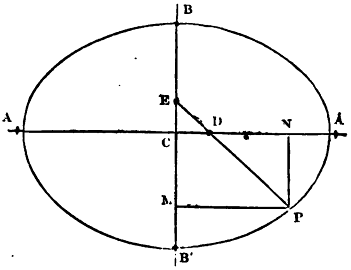
We are now in a position to trace and measure the exact pressure of the steam or vapour upon *one* side of the piston during a complete stroke up and down the cylinder; by a similar process we can determine the pressure upon the opposite side of the piston, and thus we can estimate accurately the mean pressure of the steam during a stroke, and by consequence the work done by the engine.

The horse power is obtained by multiplying this mean pressure in pounds into the number of feet traversed by the piston in one minute and dividing by 33,000, the number of pounds that a horse can raise through one foot in one minute.

132. The *oval chuck* gives another example of aggregate motion. It is based upon the following property of an oval or ellipse :—

Let A C A′, B C B′ (Fig. 163.) represent two grooves at right angles to each other, and traced upon a plane surface; P D E, a rod furnished with pins at D and E : if this rod be moved into every possible position which it can assume while the pins remain in the groove, the point P will describe an ellipse.

Fig. 163.



Draw P N $\perp^r$ to A C and P M $\perp^r$ to C B

Let $\quad$ C N $= x$, $\quad$ P E $= a$

$\qquad$ P N $= y$, $\quad$ P D $= b$

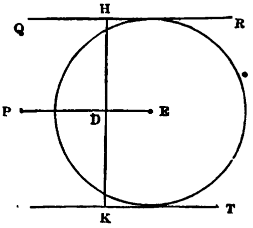
$$\text{Then } \frac{x}{a} = \frac{\text{PM}}{\text{PE}} \quad \frac{y}{b} = \frac{\text{PN}}{\text{PD}} = \frac{\text{EM}}{\text{PE}}$$

$$\therefore \frac{x^2}{a^2} + \frac{y^2}{b^2} = \frac{\text{PM}^2 + \text{EM}^2}{\text{PE}^2} = 1$$

which is the equation to an ellipse.

133. In drawing an ellipse we should fix the paper and move the rod over it, but in turning an ellipse in a lathe we should fix the describing tool and move the piece of wood or metal underneath it; thus the conditions of the problem become changed, and the construction is modified accordingly.

Fig. 164.

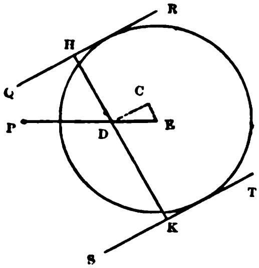


An equivalent for the grooves A C A′, B C B′ may be found as follows:

Describe a circle about E of radius larger than E D, (Fig. 164.) and let two parallel bars Q R, S T be connected by a perpendicular link H K equal in length to the diameter of the circle, and thus form a rigid frame embracing the circle, and capable of moving round it.

As the frame moves round the circle let H K pass through D in every position as represented in Fig. 165; draw D C // to Q R, and E C / to H K, then it is not difficult to understand that the triangle D C E in Fig. 165, is exactly the same as the triangle D C E in Fig. 163, and that as we formerly moved the bar E P over a plane and described an ellipse, so now we have the same motion with a fixed bar and a moveable plane, and obtain precisely the same curve.

Fig. 165.



This is a very good example of aggregate motion. The plane upon which the ellipse is traced is the subject of two simultaneous movements; a line, H K, in the plane is made to revolve by the one round D as a centre, and by the other the same line receives a sliding motion in alternate directions through D.

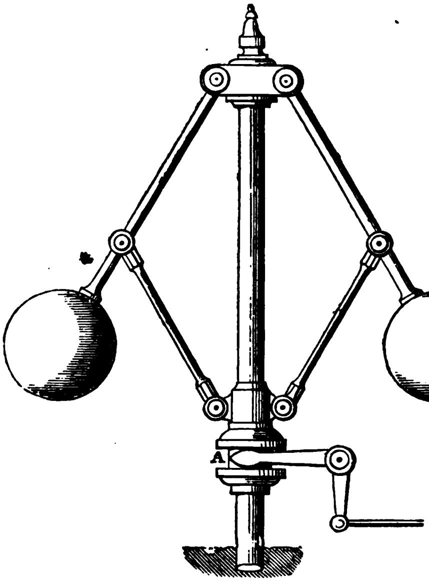
Thus an oval may be turned in the lathe.

134. The governor of a steam-engine usually appears under the form invented by Watt, and has proved of the greatest possible value in steam machinery.

The annexed diagram (Fig. 166.) shows the construction of this appendage to an engine, and the principle of its action is briefly the following:—

The engine imparts rotation to the balls of a heavy conical pendulum, and maintains them at a certain inclination to the vertical; if the velocity of the engine be increased, the balls open out more widely; if it be diminished, they collapse, and in doing so they move the end, A, of a system of levers which is connected with a throttle valve, and thereby regulate the supply of steam to the cylinder.

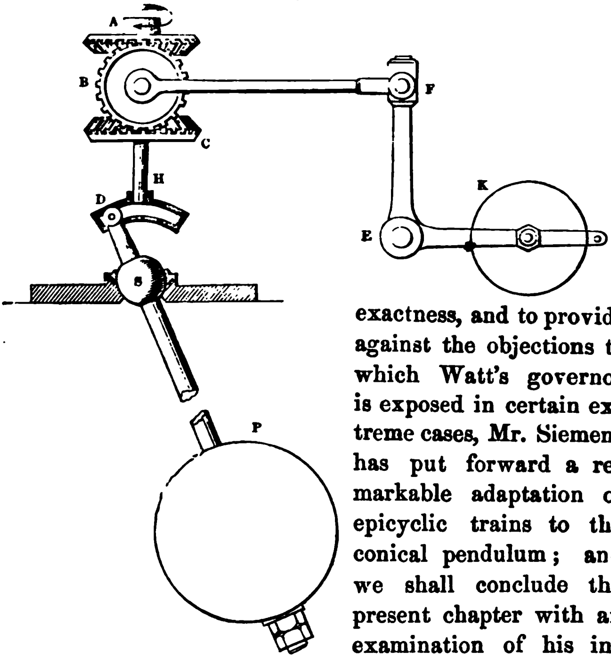
Fig. 166.



An engineer can easily arrange that the variation in speed admitted by the governor shall not exceed one-tenth of the mean velocity, but it is of the essence of the invention that some change in the speed should be admissible: the balls cannot alter their position unless the time of a revolution changes, and they cannot accumulate such additional momentum as may be sufficient to move the valve until the rate of the engine has sensibly altered.

In some cases, as where the engine drives machinery for very fine spinning, it may be desirable to obtain an almost absolute uniformity of motion; or, again, it may be an object to avoid the fluctuations in speed to which the common governor is liable when any sudden change occurs in the load upon the engine.

Fig. 167.



In order to control the engine with almost theoretical exactness, and to provide against the objections to which Watt's governor is exposed in certain extreme cases, Mr. Siemens has put forward a remarkable adaptation of epicyclic trains to the conical pendulum; and we shall conclude the present chapter with an examination of his invention.

The original construction of this governor is exhibited in the diagram, (Fig. 167.) and is better suited to the purpose of explanation than a more recent arrangement.

An epicyclic train of three equal wheels, A, B, C, imparts motion to the conical pendulum; of these, A is driven by the engine, and B is capable of running round A and C to a small extent defined by stops, the joints at F and B being so constructed as to permit of such a motion.

The wheel B (Fig. 167.) is also connected by the system of levers to a weight, K, and shuts the steam valve when its motion has lifted K through a certain space.

The valve spindle passes through the centre of motion, E, and is turned by the arm F E.

A conical pendulum, D P, is suspended by a ball and socket joint at S, and the extremity D moves in a circular groove, D H.

A certain amount of maintaining force is absorbed in preserving this pendulum at a constant angle with the vertical, and it is a part of the contrivance to increase artificially the friction which opposes the motion of the pendulum, and thus finally to make the pressure exerted by the weight, K, an actual measure of the amount of such maintaining force.

The governor is at work when the velocity of the engine suffices to keep K raised through a small space.

In order to understand the peculiar action introduced by the epicyclic train, we should remember that one of these two things will happen: either A and C will turn at the same rate, or else B will shift its position and run round the axis A H; there can be no departure from the rigid exactness of this statement.

Now the wheel C is connected with the pendulum, and its rotation cannot be maintained without a constant expenditure of force; in other words, the tendency of C is to lag behind A, and to cause B to run round the axis A H.

This indisposition in C to accept the full velocity of A is artificially increased by the friction until B shifts its position and raises the weight K permanently, and then of course it follows that the pull of K evidences itself as a constant pressure tending to drive the wheel C.

The pendulum being in this manner retained in permanent rotation, suppose that any increase were to occur in the velocity of A, the wheel C is in connection with a heavy revolving body, and can only change its velocity gradually, but K is already lifted, in the sense of being counterpoised, and the smallest increase of lifting power can therefore raise it higher; thus the tendency to an increase in the velocity of A will at once cause B to change its position, and will control the steam valve.

So sensitive is this form of governor to fluctuations in speed that an alteration of $\frac{1}{50}$th of a revolution may suffice to close the throttle valve altogether. The power to move the valve spindle is also very great, and offers a remarkable contrast to that exerted in other arrangements.

In the method now adopted at Greenwich for registering the times of transit of the stars by completing a galvanic circuit at the instant of observation, a drum carrying a sheet of paper is made to revolve once in two minutes. A pricker actuated by an electro-magnet, and moving slowly in a lateral direction, is set in motion at the end of each beat of the seconds' pendulum of a clock, and thereby makes a succession of punctures in a spiral thread running round the drum. The observer touches a spring at the estimated instant of the time of transit of a star across a wire of the telescope, and producing a puncture intermediate to those caused by the pendulum, does in fact record the exact period of the observation. The regularity of motion in the drum is a matter of vital importance, and is ensured by the employment of a clock train moving under the control of this pendulum of Mr. Siemens.

CHAP. VI.

MISCELLANEOUS CONTRIVANCES.

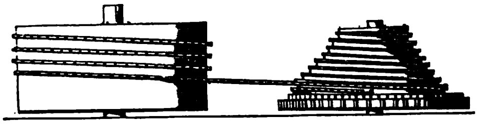
We propose to examine in our concluding chapter various miscellaneous pieces of mechanism, and certain special contrivances which are of frequent occurrence in machinery, and with which a student of applied mechanics ought to render himself familiar.

135. *The Fusee* is adopted in chronometers, and in most English watches, in order to maintain a uniform force upon the train of wheels, and to compensate for the decreasing power of the spring.

The spring is enclosed in a cylindrical barrel, and sets the wheels in motion by the aid of a chain wound partly upon the barrel and partly upon a sort of tapering drum called a fusee. (Fig. 169.)

As the spring uncoils in the barrel the pull of the chain decreases in intensity; at the same time, however, the chain unwinds itself from the fusee, and continually exerts its strain at a greater distance from the axis, *i.e.* with a greater leverage, and with more effect.

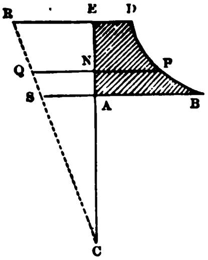
Fig. 169.



The theoretical form of the fusee is an hyperbola.

Let D P B (Fig. 170.) represent the generating curve of a fusee, E A being its axis.

Fig. 170.



Draw D E, P N, B A perpendiculars on E A; take E R, Q N, S A to represent the pull of the spring when the chain is at D, P, B respectively.

According to Hooke's Law, "ut tensio sic vis," the force of the spring decreases uniformly, and ∴ R Q S is a straight line; produce it to meet E A in C, and let $CN = x$, $NP = y$. Now the fusee will accomplish its object if (the pull of the spring) × (arm N P) remains constant for every position of P.

But the pull of the spring $\propto QN \propto CN$ or $= mx$

$$\therefore (mx)\,(\text{arm } NP) = \text{a constant quantity}$$

or mxy = a constant, or xy = a constant, which is the equation to an hyperbola.

136. In mechanism the fusee is frequently employed to transmit motion instead of to equalise force, and enables the mechanic to derive a continually increasing or decreasing circular motion from the uniform continuous rotation of a driving shaft.

The groove of the fusee may be traced upon a cone or other tapering surface, or it may be compressed into a flat spiral curve: in all cases the effect produced will be that due to a succession of arms which radiate in perpendicular directions from a fixed axis, and continually increase or decrease in length.

The fusee can of course only make a limited number of turns in one direction.

137. A *Flat Spiral Fusee* occurs in spinning machinery, and serves to regulate the velocity of the spindles, and to ensure the due winding of the thread in a succession of conical layers upon a bobbin or "*cop*."

The formation of the *cop* is a problem upon which a vast amount of mechanical ingenuity has been expended; and, without entering too much into details, we may observe that there are two distinct stages in the process of winding the yarn upon a spindle so as to produce a finished cop.

The *Copbottom* (Fig. 171.) is first formed upon a bare spindle by superposing a series of conical layers of continually increasing vertical angle.

The body of the cop is then built up by winding the yarn in a series of equal conical layers. (Fig. 172.)

The winding on of the yarn begins at the base of the cone, and proceeds upwards to the vertex: the spindles are driven by a drum which rotates under the pull of a chain, and it is evident that they can be made to revolve with increasing rapidity by placing a fusee upon the driving shaft and causing the chain to coil upon it.

Fig. 171.

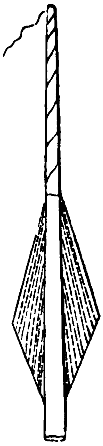
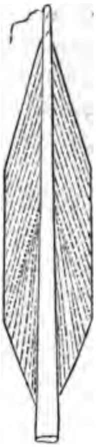
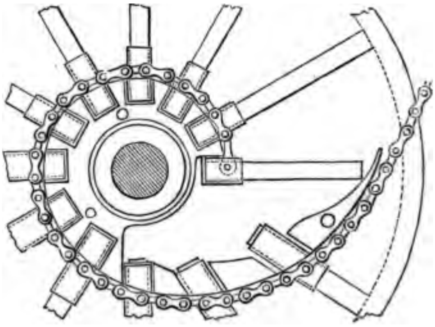


Fig. 172.



Such an arrangement, as shown in Fig. 173, will be adapted to the winding of a uniform supply of thread upon a conical surface; and we can easily comprehend that a fusee of fixed dimensions will do very well for building up the body of

Fig 173.

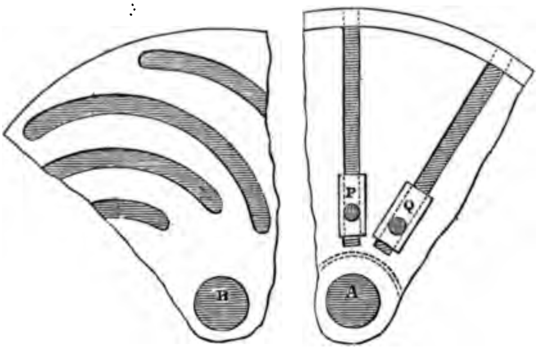


the cop after the foundation is made. The main difficulty occurs in producing the cop bottom, where the series of conical layers of continually increasing vertical angle demands a fusee whose dimensions shall gradually contract.

The method of contracting the form of the fusee may be explained as follows:—

Fig. 174. represents portions of two flat discs having axes at A and B, and upon which are cut radial and curved grooves in the manner indicated; it being arranged that when one plate is placed upon the other the pins P and Q shall travel in both sets of grooves at the same time.

Fig. 174.



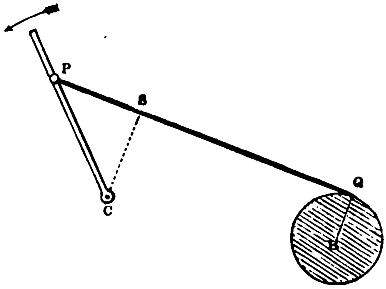
We can easily see that the blocks which carry the pins will move along the radial grooves as the disc B turns relatively to A, and that by this combination we can obtain a spiral fusee of any required form, and can contract or enlarge its dimensions at pleasure.

138. *Mr. Roberts' "winding-on motion"* reposes upon the principle of the fusee, though in a modified form.

Let one end of a rope which is coiled round a drum be attached to a point, P, (Fig. 174.) in the moveable arm

C P: it is evident that the rotation of C P about the centre C will cause some portion of the rope to be unwound from the barrel.

Fig. 175.

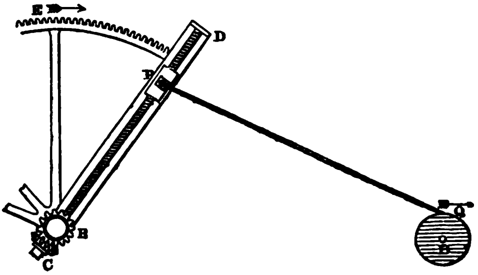


Draw C S $\perp^r$ to the direction of the rope, then at any instant of the motion the arrangement supplies the jointed rods, C P, Q B, mentioned in Art. **52**, and it is manifest that the rate at which the string is unwound will vary as the perpendicular C S.

This rate is greatest when C P is $\perp^r$ to P Q, but decreases to nothing when C S vanishes, and here, therefore, the fusee exists in a latent form.

Next conceive that the conditions are changed, and that the drum B moves to the right hand through a moderate space while C P remains fixed (Fig. 176.); the cord will unwind from the drum with a nearly uniform velocity.

Fig. 176.



If, finally, the arm C P be not fixed, but be made to move from a position a little to the left of the vertical into one nearly horizontal during each journey of the drum, it is abundantly clear that we shall subtract from the uniform motion of unwinding that amount which is due to the action of a fusee, and that if the spindles derive their motion from the rotation of the drum they will continually accelerate as the drum recedes from C P. In this way we can make up the body of the cop. To form the cop bottom it is necessary that the winding on should begin more rapidly, and should gradually diminish; this character of motion is produced by causing the nut P to traverse C D in successive steps during each journey of the drum. As soon as the cop has attained its full diameter, the nut ceases to travel along C D, and the thread is wound in uniform conical layers.

139. If two cords be wound in opposite directions round a drum A, (Fig. 176.) and the ends of the cords be fastened to a moveable carriage, it is evident that the rotation of A in alternate directions will cause a reciprocating movement in the carriage.

Fig. 176.

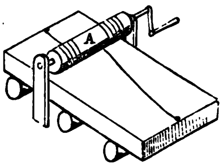
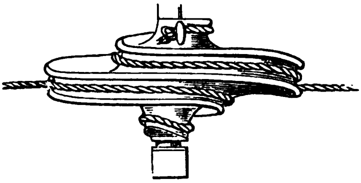


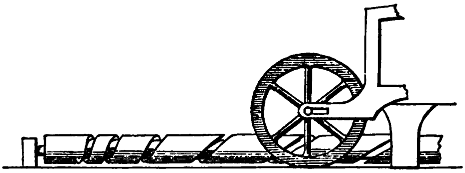
Fig. 177.



The drum A, (Fig. 178.) has been replaced by a spiral fusee in the self-acting mule of Mr. Roberts, and thus the motion of the carriage is gradually increased till it has reached the middle of its path, and then decreases to the end of the movement.

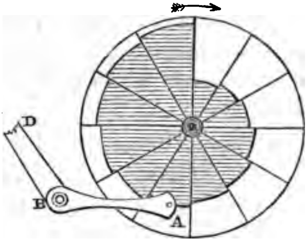
140. A helical screw of a varying pitch traced upon a cylinder would produce a similar variable motion of the mule carriage, and has been applied in a machine constructed upon a different principle, in order to obtain a continually decreasing motion of the carriage. In effect it replaces the fusee.

Fig. 178.



141. The *snail* is chiefly found in the striking part of repeating clocks. It is a species of fusee, and is used to define the amount of angular deviation of a lever A B (Fig. 179.)

Fig. 179.

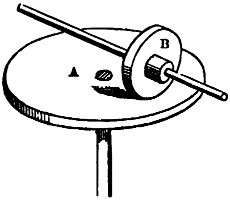


A circle is divided into a number of equal parts, 12 for example, and a series of steps are formed by cutting away the plate and leaving a circular boundary in each position.

As the snail revolves, B D passes by jerks into twelve different positions, and performs the function required of it.

142. The *disc and roller* is equivalent to the fusee, and is now but little used on account of the probability that the roller will occasionally slip.

Fig. 180.

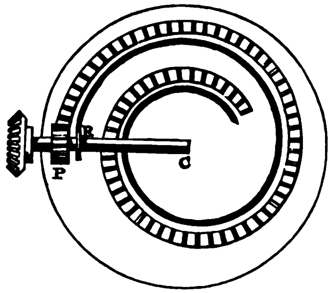


This arrangement consists of a disc A, (Fig. 180.) revolving round an axis $\perp^r$ to its plane and giving motion to a rolling plate B, fixed upon an axis which intersects at right angles the axis of the disc A.

Supposing the rotation of the disc to be uniform, that of the roller B will continually decrease as it is shifted towards the centre of A, and conversely.

This is precisely the effect produced by a fusee.

Fig. 181.



The roller may be a wheel furnished with teeth, and may roll upon a spiral rack, as shown in Figure 181.

As the disc revolves, the pinion P slides upon the square shaft, and is kept upon the rack by the action of a guide roller R, which travels along the spiral shaded groove.

This example is by no means put forward as a good mechanical contrivance.

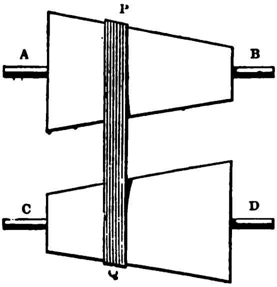
143. In the transfer of motion from one axis to another, it often happens that we wish to deduce a rotation which may be made greater or less from one which is perfectly uniform.

Conical Pulleys will give this result, and are represented in figure 182 where two cones moveable about the axes A B, C D, are connected by a driving band P Q.

The rotation of A B being uniform, it is at once evident that the rotation of C D will continue to decrease as the strap is shifted from C towards D.

One of the cones is sometimes replaced by a cylindrical drum, in which case the strap must be kept stretched by a tightening pulley.

Fig. 182.

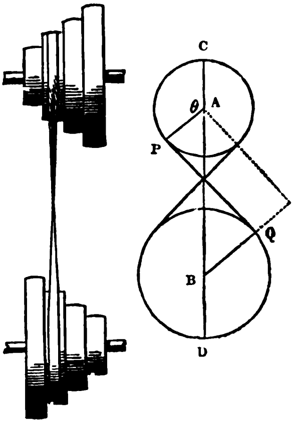


Speed Pulleys form one variety of conical pulleys, and are so called because they allow of the transfer of different velocities of rotation from one shaft to another; they are much used in engineers' factories.

They are made in a series of steps, as shown in the figure, and it very commonly happens that they are connected by an open band.

There is a peculiarity when the band is crossed which does not exist otherwise, and we shall now show that the same band, when crossed, will be sure to suit every pair of pulleys which are connected by the simple relation that the sum of the radii of each opposite pair is equal to a constant quantity.

Fig. 183.



This gives a very easy rule for making the pulleys, and the proof is the following:

Let a pair of pulleys be represented in Fig. 183, and let $AP = x$, $BQ = y$, $PAC = DBQ = \theta$,

$$\begin{aligned} \text{Then } CPQD &= x\theta + y\theta + PQ \\ &= (x + y)\theta + AB \sin\theta. \end{aligned}$$

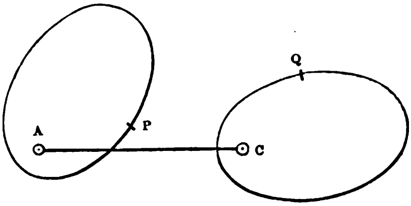
But $x + y$ is supposed to be constant.

$\therefore$ $CPQD$ is quite independent of the relative size of the pulleys, and only changes when θ, or AB, changes.

144. *Rolling Curves* have been employed to vary the relative angular velocity of two revolving pieces.

The guiding proposition connected with this subject is the following :—

Fig. 184.



Prop. Where two curved plates, centred upon fixed axes, roll together, the point of contact must always lie in the line of centres.

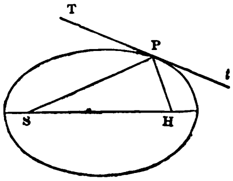
Let two such plates be centred at A and C (Fig. 184.) and suppose that P and Q represent two points which will be in contact when the curves roll.

Then P describes a circle round A as the plate revolves, and Q describes a circle round C; hence P and Q will come into contact whenever these circles meet each other. Now P and Q only meet once in one revolution, and therefore the circles can only meet once, *i.e.* they touch each other. But the circles can only touch in the line A C, therefore the point of rolling contact must lie in A C.

Cor. This is equivalent to saying that A P + C Q = a constant quantity. Further than this, the curves will have a common tangent at the point where they roll upon each other.

Ex. Two equal ellipses which are centred on opposite foci will roll together.

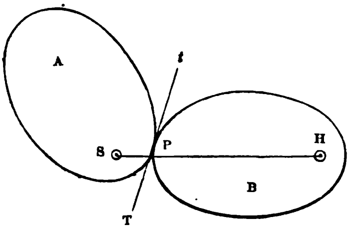
Fig. 185.



It is the property of an ellipse that the tangent at any point P makes equal angles with S P and H P, and again that the sum of the lines S P and H P is a constant quantity. (Fig. 185.)

The two equal ellipses centred upon opposite foci are represented in contact at P. (Fig. 186.)

Fig. 186.

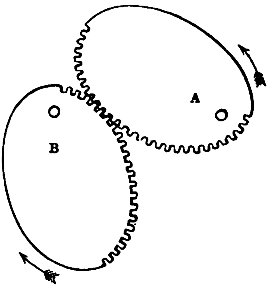


Let P T be the tangent to the ellipse A at P, and P *t* the tangent to the ellipse B at P.

Then S P T = *t* P H by the property above stated, ∴ T P *t* is a straight line or the curves have a common tangent at the point P. Also S P + H P = a constant quantity, and the two conditions of rolling are fulfilled.

145. In practice rolling curves must be provided with teeth upon the retreating edge, otherwise the driver would leave the follower, and the revolution would not be completed. (Fig. 187).

Fig. 187.



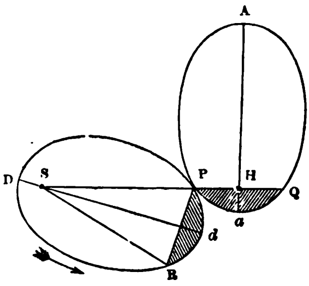
As is usual in all cases where segmental wheels are employed, a guide must direct the teeth to the exact point where they commence to engage each other.

The guide may be dispensed with by carrying the teeth all round the curves: this construction is usually adopted in practice, although, strictly speaking, it destroys the rolling action entirely.

146. A quick return of the table in small planing machines is effected by the aid of rolling ellipses.

The table is driven by a crank and connecting rod, and the crank exists under the form of a flat circular plate, centred on one of the foci, and having a groove radiating from the axis as a line of attachment for one end of the connecting rod. As the plate may be set in any position upon the elliptical wheel, we propose to inquire what will be the effect of a change of direction in the groove or crank.

Fig. 188.



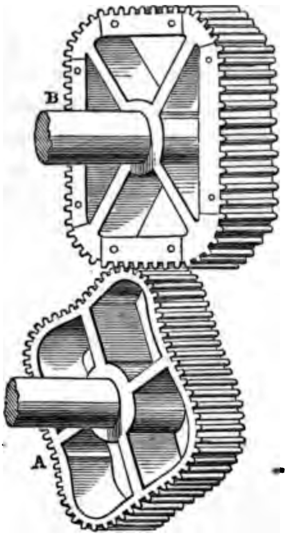
Let the ellipses have the position shown in Figure 188, S and H being the centres of motion, and S P H Q being $\perp^r$ to A a, the axis of one ellipse. Draw P R $\perp^r$ D d, and let the ellipse D R d P be the driver, rotating in the direction of the arrow.

While P d R is rolling upon P a Q the ellipse A a makes half a revolution, and while R D P is rolling upon Q A P, it makes the remaining half revolution.

Suppose D *d* to revolve uniformly, then the times of a half revolution of A *a* will be in the same proportion to each other as the angle P S R to the angle 360 — P S R. The quick half revolution occurs when the shaded segments are rolling upon each other. If, therefore, the table be made to move in the line H S produced, and the crank be placed in a direction $\perp^{r}$ A *a* we shall obtain the greatest possible difference between the periods of advance and return.

The practical difficulty with rolling wheels exists during that part of the revolution where the driver tends to leave the follower, and it can only be obviated by making the teeth unusually deep.

Fig. 189.



147. An instance of rolling curves is exhibited in Fig. 189, and occurred in one of the many attempts made to improve the printing press before the invention of Mr. Cowper enabled the newspapers to commence a real and vigorous existence.

The type was placed upon each of the four flat sides of a rectangular prism to which the wheel B corresponded in shape, and the paper was passed on to a *platten* corresponding in form to the wheel A.

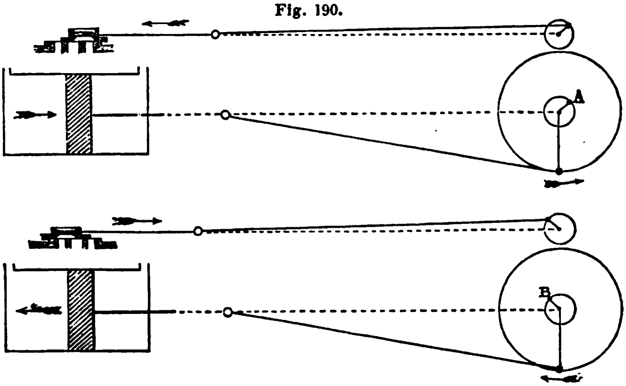
The prism and platten being in the same relative position as the wheels B and A, we can understand that the type would be in the act of impressing the paper while the convex edge of the wheel A rolled upon the flat side of B, and that in this way we should obtain four impressions for each revolution of the wheels.

148. *The Double Eccentric for reversing an Engine.* In a Locomotive or Marine Engine the relative positions of the piston and steam valve would be such as are indicated in the diagram. (Fig. 190.)

The small circle gives the path of the centre of the eccentric pulley, and the large circle that of the centre of the crank pin.

In the upper diagram of Fig. 190 the piston is moving to the right and the valve to the left; if we are to reverse the motion, we must drive the piston back by admitting the steam upon the opposite side, and by letting out that portion of the steam which is urging the piston forward. Hence we must move the valve into the position shown in the lower diagram, and shift A to B; the piston will then return before it reaches the end of the cylinder, and the movement of the engine will be reversed.

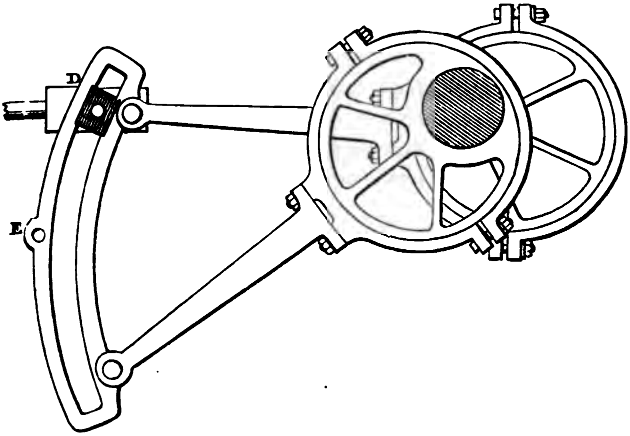
Fig. 190.



The double eccentric enables us to accomplish this change; it consists of two eccentrics keyed upon the crank shaft (Fig. 191.) and so united that their rods terminate in a circular link or grooved bar which is suspended by levers, and is capable of taking such extreme positions as to connect the valve either with one eccentric or the other.

It possesses the additional advantage that when the moveable piece D, which is attached to the end of the slide rod, occupies any intermediate position in the link, a reduced motion is imparted to the valve, and the speed of the engine is lessened.

Fig. 191.



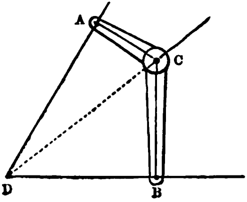
The link is suspended by levers at the point E, and is capable of being moved so as to shift D throughout its length.

149. *Bell Crank Levers* serve to change the line of direction of some small motion, and are of universal application. They consist simply of two arms standing out from a fixed axis so as to form a bent lever.

1. Let the two lines of direction lie in one plane and meet in some point D, (Fig. 192.); draw D C, dividing the angle at D into two parts whose sines are in the ratio of the velocities of the movements in the given directions.

In D C take any convenient point C, and draw C A, C B, $\perp^r$ to D A and D B, then A C B will be the bell crank required.

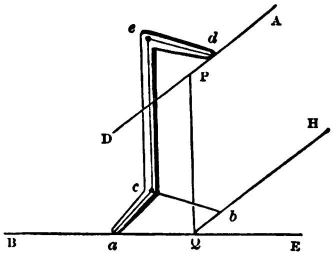
Fig. 192.



It is evident that the velocities of A and B are directly as the arms C A, C B, *i.e.* in the ratio of sin C D A to sin C D B.

The motion in D A or D B becomes more nearly rectilinear the further we remove C from the point D.

Fig. 193.



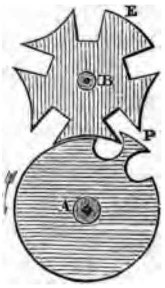
2. Let the lines of direction pass without meeting each other.

Draw P Q, a common $\perp^r$ to the lines A D and B E, (Fig. 193.), through Q draw Q H // D A; construct a bell crank lever, *a c b*, for the movements as transferred to the lines B Q, Q H; draw *c e* // to P Q and equal to it, and further make *e d* // and equal to *c b*.

The piece *a c e d* will be the lever required.

150. Where a train of wheels is set in motion by a spring enclosed in a barrel, it becomes of consequence not to overwind the spring, and the *Geneva stop* has been contrived with the view of preventing such an occurrence.

Fig. 194.



The peculiar form is shown in the figure.

A disc A, (Fig. 194.) furnished with one projecting tooth P, is fixed upon the axis of the barrel and is turned by the key.

Another disc B, shaped as in the drawing, is turned through a certain space every time that the tooth P passes through one of its openings and is held fast at other times by the convex surface of A.

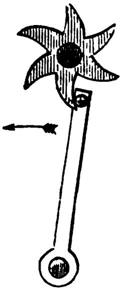
In this manner each rotation of A will advance B through a certain space, and the motion will continue until the convex surface of A meets the convex portion E, which is allowed to remain upon the disc B in order to stop the winding up.

The winding action having ceased the discs will return to their normal positions as the mechanism runs down.

151. The *Star wheel* is much used in cotton spinning machinery, and is analogous to the Geneva stop.

If the convex portion E were removed so as not to interfere with the rotation of A, we should virtually possess a star wheel in B.

Fig. 195.



In that case each rotation of A would advance B by the space of one tooth, or we should convert a continuous circular motion into one of an intermittent character.

The usual form of the star wheel is given in Figure 195, where the revolving arm encounters and carries forward a tooth at each revolution.

It is as if a wheel with one tooth were to drive another with several teeth.

152. The invention of *counting wheels* is due to the celebrated Cavendish, who constructed a piece of apparatus for registering the number of revolutions of his carriage wheel.

There is but one guiding principle in this branch of mechanism, however varied may be the details of the separate parts.

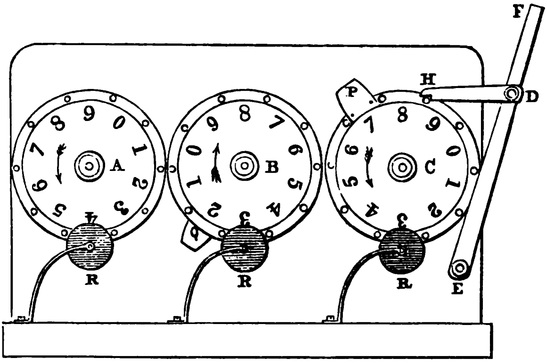
Each wheel of a series A, B, C, &c. possesses ten pins or teeth, and it is contrived that one tooth only of C shall be sufficiently long to reach those of B; similarly B is provided with one long tooth which is capable of driving A.

Thus C goes round ten times while B makes one revolution, and so on for the other wheels; in this way the series is adapted for counting units, tens, hundreds, thousands, &c.

In the figure the arm E F (Fig. 196.) imparts rotation to the first wheel by the assistance of the click H D; the number registered is 988: after two vibrations of the arm the zero of C will reach the highest point, the tooth

P will drive B through the space of one tooth; and the number registered will be 990; after 10 more vibrations of the arm, P will again advance B, and at the same instant Q will move A, and will bring up its zero to the highest point. The three wheels will now register 000, having passed the number 999 which is the last that they can give us.

Fig. 196.



Where it is intended to print the figures registered as in the numbering of Bank notes, each wheel must carry the letters on the edge and not upon the face, the principle is the same, but the construction differs, the wheels being placed side by side, and close together.

One principal feature in this contrivance is the reduction in motion caused by the single driving tooth. Now, we have seen in page 6 that an endless screw is equivalent to a wheel with one tooth, and we shall therefore be prepared to find that an endless screw is useful in mechanism of this character.

There is an ingenious contrivance known as the *differential worm wheel and tangent screw,* which may be noticed very briefly. Two worm wheels, differing by one tooth in the number which they carry, are placed side by side and close together, so as to be capable of engaging with a single endless driving screw. It is apparent that one wheel will turn relatively to the other through the space of the extra tooth in a complete revolution, and that a very slow relative motion will be introduced.

In this way, if one wheel carries a dial plate, and the other a hand, we can obtain the record of a very large number of revolutions of the tangent screw.

153. If the end Q of the connecting rod in Art. 4 be attached to a *knuckle* or *toggle joint* D Q E, consisting of two bars jointed at Q, we derive a combination which has been used for many purposes.

Let D (Fig. 197.) be fixed, and when P comes to B, let D Q E straighten itself into the line D R; the point E is commonly constrained to move in the line D R, and great pressure may be exerted at E when D Q E becomes very nearly a straight line.

Fig. 197.

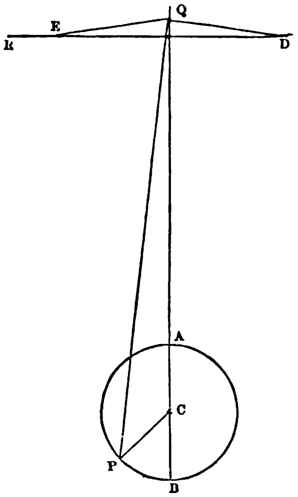
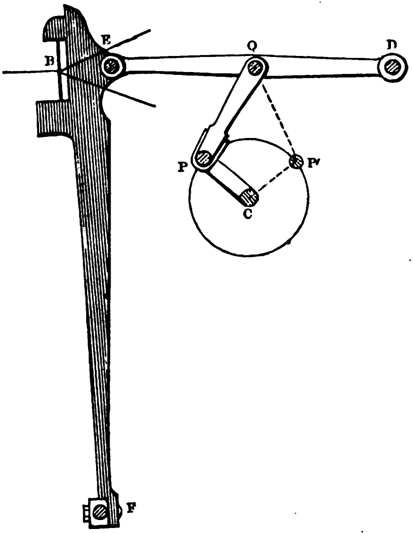


Fig. 198.



In general D Q E straightens itself when P is at B, *i.e.*

once for each revolution of the crank C P; but if C be shifted a little towards the joint, the point Q will descend below the line, R D, and we shall arrive at two positions of P in which D Q E becomes a straight line.

Fig. 198 is intended to show the toggle joint as applied to a movement of this character in a Power Loom.

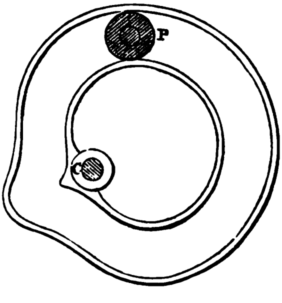
In weaving, the thread of the weft requires to be beaten up into its place after each throw of the shuttle; and in some cases, as in carpet weaving, two beats are wanted instead of one.

The combination under discussion has been used to actuate the moveable swinging frame, or batten, which beats up the weft, and the result is that two blows are given in rapid succession.

In the figure now referred to, E F is the batten, moveable about F as a centre, and it is clear that when the crank takes the positions C P, C P′, the toggle joint D Q E will straighten, and, as a consequence, the batten will be pushed as far as it can go to the left hand, or a beat up of the weft will take place.

By referring to Chap. I. we shall understand that a cam plate moveable about C, (Fig. 199.), and shaped as in the figure, may be employed to drive the batten, and may replace the above combination.

Fig. 199.

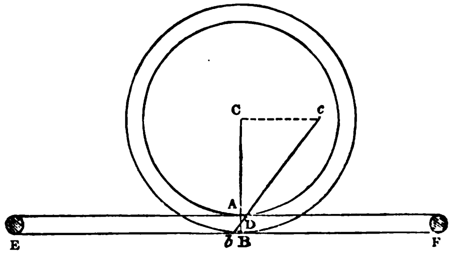


The roller P is connected with some levers attached to the batten, and the beat up occurs when P passes through the hollows upon each side of the projecting portion of its path upon the plate.

154. *Saxton's Differential Pulleys* were patented in 1832, with a view of obtaining great speed in railway carriages propelled by a rope: by the use of this invention the consumption of the rope, proposed to be wound up at a stationary engine house, would be much less than if the carriage were attached in the ordinary way.

Let two wheels of different diameters (say as 6 to 7) be centred on a common axis at C (Fig. 200.) and be fastened together, and let an endless rope be wound round the wheels and pass over pulleys at E and F in the manner shown in the diagram, the rope taking a turn round each of the pulleys.

Fig. 200.



Conceive now a pull to be exerted on the rope at B in the direction B E, then the tension of the string will cause an equal and opposite pull to arise at A in the direction A F, and thus the compound pulley has a tendency to turn about D, the middle point of A B.

This tendency in the pulley to turn about the point D causes the linear motion of C to be very much greater than that of any point in the rope; for example, when B moves through a small space, B *b*, C will advance through C *c*, which upon our supposition is 13 times as great, so that when one yard of rope is wound up the carriage will have travelled through 13 yards.

The carriage may be at once stopped by disconnecting the pulleys.

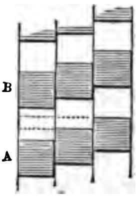
155. *Step Wheels* constitute a modification of toothed wheels; they are due to Dr. Hooke, and are used to ensure a smooth action in certain combinations of wheel work.

It is evident that the action of two wheels upon each other becomes more even and perfect when the number of teeth is increased, but that the teeth at the same time become weaker and less able to transmit great force.

Dr. Hooke's invention overcomes the difficulty, and virtually increases the number of teeth without diminishing their strength.

Several plates or wheels are laid upon one another so as to form one wheel, and the teeth of each succeeding plate are set a little on one side of the preceding one, it being provided that the last tooth of one group shall correspond within one step to the first tooth of the next group. The principal part of the action of two teeth occurs just as they pass the line of centres, and there are now three steps instead of one from the tooth A to the tooth B. (Fig. 201.)

Fig. 201.

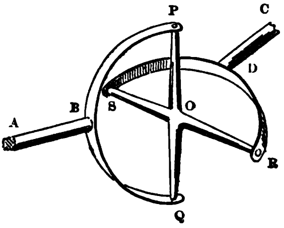


A single oblique line might replace the succession of steps, but we should then introduce a very objectionable endlong pressure upon the bearings of the wheels.

156. *Hooke's Joint* is a method of connecting two axes, whose directions meet in a point, in such a manner that the rotation of one axis shall be communicated to the other.

A B and C D (Fig. 202.) represent two axes whose directions meet in the point O; the extremities of A B and C D terminate in two semicircular arms which carry a cross, P Q S R; the arms of this cross are perfectly equal, and it is jointed at P, Q, S, and R, so as to have the necessary freedom of motion.

Fig. 202.

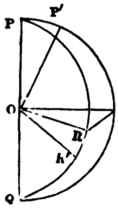


As the axis A B (Fig. 202) revolves, the points P and Q describe a circle whose plane is $\perp^r$ to A B, and at the same time S and R describe another circle whose plane is $\perp^r$ to C D.

These two circles are inclined at the same angle as the axes, and are represented in figure 203; thus the point P starts from P and moves in the circle P P′ Q, while the point R starts from R and describes the circle R R′ Q.

Let O P′, O R′ be corresponding positions of the two arms, then P′ R′ is constant, but changes its inclination at every instant, and as a consequence the relative angular velocities of O P′ and O R′ are continually changing.

Fig. 203.



To find the relative angular velocities of the axes A B and C D we proceed as follows:

Let the circle $p\,r\,q$ (Fig. 204.) represent the path of P, $p\,t\,q$ being the projection upon this circle of the path of R, and suppose θ to be the angle between A B and C D; then the dimensions of the curve $p\,t\,q$, which will be an ellipse, can be at once deduced from the equation $\text{O}\,t = \text{O}\,r\cos\theta$.

Draw R m $\perp^r$ O r, then R m will be the actual vertical space through which R has descended while O P describes the $\angle\, p$ O P. But the path of R is really a circle, and only appears to be an ellipse by reason of its projection upon

Fig. 204.

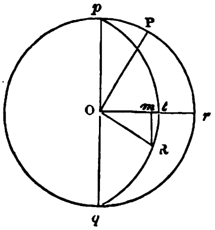


Fig. 205.

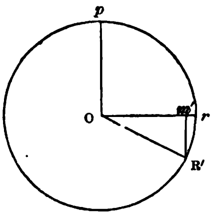
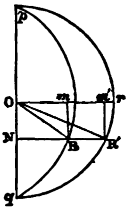


Fig. 206.



a plane inclined to its own plane; in order, therefore, to estimate the actual angular space through which O R has moved, we must refer this motion to the circle which R really describes, (Fig. 205.) and thus by making $R'm' = Rm$ we shall find that $m' O R'$ will be the angle which $O R$ describes while $O P$ moves through the angle $p\, O\, P$.

We may represent the motion of both axes upon one diagram by combining the ellipse $p\, R\, q$ with the circle $p\, r\, R'$, if we then draw $N R R' \perp^{r} p\, O\, q$ and join $O R$, $O R'$, it will be easy to see that the angles $R O r$, $R' O r$ are those described in the same time by the axes $A B$ and $C D$. (Fig. 206.)

Hence the axes $A B$, $C D$ revolve together, but unequally, and the angles which they describe in the same time will be at once apparent upon referring to the positions of $O R$, $O R'$ at any period of the motion.

Furthermore, $O R$, $O R'$ coincide when R is at the end of an axis of the ellipse $p\, R\, q$, an event which happens four times as the cross goes round once, and there is therefore this curious result, that however unequally the axes revolve they must coincide in relative position four times in one revolution.

THE END.

LONDON
PRINTED BY SPOTTISWOODE AND CO.
NEW-STREET SQUARE.

A CATALOGUE
OF
NEW WORKS IN GENERAL LITERATURE

PUBLISHED BY

LONGMAN, GREEN, LONGMAN, AND ROBERTS

39 PATERNOSTER ROW, LONDON.

CLASSIFIED INDEX

Agriculture and Rural Affairs.

Bayldon on Valuing Rents, &c.	6
“ on Road Legislation	6
Caird's Prairie Farming	8
Cecil's Stud Farm	8
Hoskyns's Talpa	11
Loudon's Agriculture	14
Low's Elements of Agriculture	14
Morton on Landed Estates	17

Arts, Manufactures, and Architecture.

Brande's Dictionary of Science, &c.	6
“ Organic Chemistry	6
Cresy's Civil Engineering	8
Fairbairn's Information for Engineers	9
Gwilt's Encyclopædia of Architecture	10
Harford's Plates from M. Angelo	10
Humphreys's *Parables* Illuminated	12
Jameson's Sacred and Legendary Art	13
“ Commonplace-Book	13
König's Pictorial Life of Luther	10
Loudon's Rural Architecture	14
Mac Dougall's Campaigns of Hannibal	15
“ Theory of War	15
Moseley's Engineering	17
Piesse's Art of Perfumery	18
Richardson's Art of Horsemanship	19
Scoffern on Projectiles, &c.	20
Steam Engine, by the Artisan Club	6
Ure's Dictionary of Arts, &c.	23

Biography.

Arago's Lives of Scientific Men	5
Baillie's Memoir of Bate	6
Brialmont's Wellington	6
Bunsen's Hippolytus	7
Bunting's (Dr.) Life	7
Crosse's (Andrew) Memorials	8
Gleig's Essays	10
Green's Princesses of England	10
Harford's Life of Michael Angelo	10
Lardner's Cabinet Cyclopædia	13
Marshman's Life of Carey, Marshman, and Ward	15
Maunder's Biographical Treasury	16
Morris's Life of Becket	17
Mountain's (Col.) Memoirs	17
Parry's (Admiral) Memoirs	18
Russell's Memoirs of Moore	17
“ (Dr.) Life of Mezzofanti	20
SchimmelPenninck's (Mrs.) Life	20
Southey's Life of Wesley	21
Stephen's Ecclesiastical Biography	22
Strickland's Queens of England	22
Sydney Smith's Memoirs	21
Symonds's (Admiral) Memoirs	22
Taylor's Loyola	22
“ Wesley	22
Uwins's Memoirs and Correspondence	23
Waterton's Autobiography and Essays	24

Books of General Utility.

Acton's Bread-Book	5
“ Cookery-Book	5
Black's Treatise on Brewing	6
Cabinet Gazetteer	8
“ Lawyer	7
Cust's Invalid's Own Book	9
Hints on Etiquette	11
Hudson's Executor's Guide	12
“ on Making Wills	13
Kesteven's Domestic Medicine	13
Lardner's Cabinet Cyclopædia	13
Loudon's Lady's Country Companion	14
Maunder's Treasury of Knowledge	16
“ Biographical Treasury	16
“ Geographical Treasury	16
“ Scientific Treasury	15
“ Treasury of History	16
“ Natural History	16
Piesse's Art of Perfumery	18
Pitt's How to Brew Good Beer	18
Pocket and the Stud	11
Pycroft's English Reading	19
Rich's Companion to Latin Dictionary	19
Richardson's Art of Horsemanship	19
Riddle's Latin Dictionaries	19
Roget's English Thesaurus	20
Rowton's Debater	20
Short Whist	21
Simpson's Handbook of Dining	21
Thomson's Interest Tables	22
Webster's Domestic Economy	24
Willich's Popular Tables	24
Wilmot's Blackstone	24

Botany and Gardening.

Hassall's British Freshwater Algæ . 11
Hooker's British Flora . 11
“ Guide to Kew Gardens . 11
Lindley's Introduction to Botany . 14
“ Synopsis of the British Flora . 14
“ Theory of Horticulture . 14
Loudon's Hortus Britannicus . 14
“ Amateur Gardener . 14
“ Trees and Shrubs . 14
“ Gardening . 14
“ Plants . 14
Pereira's Materia Medica . 18
Rivers's Rose Amateur's Guide . 19
Watson's Cybele Britannica . 24
Wilson's British Mosses . 24

Chronology.

Brewer's Historical Atlas . 6
Bunsen's Ancient Egypt . 7
Haydn's Beatson's Index . 11
Jaquemet's Two Chronologies . 13

Commerce and Mercantile Affairs.

Gilbart's Logic of Banking . 10
“ Treatise on Banking . 10
Lorimer's Young Master Mariner . 14
M'Culloch's Commerce and Navigation 15
Thomson's Interest Tables . 22
Tooke's History of Prices . 22

Criticism, History, and Memoirs.

Brewer's Historical Atlas . 6
Bunsen's Ancient Egypt . 7
“ Hippolytus . 7
Chapman's Gustavus Adolphus . 8
Connolly's Sappers and Miners . 8
Conybeare and Howson's St. Paul . 8
Crowe's History of France . 9
Fischer's Francis Bacon . 9
Frazer's Letters during the Peninsular and Waterloo Campaigns . 10
Gleig's Essays . 10
Gurney's Historical Sketches . 10
Hayward's Essays . 11
Herschel's Essays and Addresses . 11
Jeffrey's (Lord) Contributions . 13
Kemble's Anglo-Saxons . 13
Lardner's Cabinet Cyclopædia . 13
Macaulay's Critical and Hist. Essays . 14
“ History of England . 14
“ Speeches . 14
Mackintosh's Miscellaneous Works . 15
“ History of England . 15
M'Culloch's Geographical Dictionary . 15
Maunder's Treasury of History . 16
Merivale's History of Rome . 16
“ Roman Republic . 16
Milner's Church History . 16
Moore's (Thomas) Memoirs, &c. . 17
Mure's Greek Literature . 17
Normanby's Year of Revolution . 18
Perry's Franks . 18
Porter's Knights of Malta . 19
Raikes's Journal . 19
Riddle's Latin Dictionaries . 19
Rogers's Essays from Edinb. Review . 19
“ (Sam.) Recollections . 13
Roget's English Thesaurus . 20
SchimmelPenninck's Memoirs of Port Royal . 20
SchimmelPenninck's Principles of Beauty 20
Schmitz's History of Greece . 20
Southey's Doctor . 21
Stephen's Ecclesiastical Biography . 22
“ Lectures on French History . 21
Sydney Smith's Works . 21
“ Lectures . 21
“ Memoirs . 21
Taylor's Loyola . 22
“ Wesley . 22
Thirlwall's History of Greece . 22
Turner's Anglo-Saxons . 23
Uwins's Memoirs and Letters . 23
Vehse's Austrian Court . 23
Wade's England's Greatness . 23
Young's Christ of History . 24

Geography and Atlases.

Brewer's Historical Atlas . 6
Butler's Geography and Atlases . 7
Cabinet Gazetteer . 8
Johnston's General Gazetteer . 13
M'Culloch's Geographical Dictionary . 15
Maunder's Treasury of Geography . 16
Murray's Encyclopædia of Geography . 17
Sharp's British Gazetteer . 21

Juvenile Books.

Amy Herbert . 20
Cleve Hall . 20
Earl's Daughter (The) . 20
Experience of Life . 20
Gertrude . 20
Howitt's Boy's Country Book . 12
“ (Mary) Children's Year . 12
Ivors . 20
Katharine Ashton . 20
Laneton Parsonage . 20
Margaret Percival . 20
Piesse's Chymical, Natural, and Physical Magic . 18
Pycroft's Collegian's Guide . 19

Medicine, Surgery, &c.

Brodie's Psychological Inquiries . 6
Bull's Hints to Mothers . 7
“ Management of Children . 7
“ Work on Blindness . 7
Copland's Dictionary of Medicine . 8
Cust's Invalid's Own Book . 9
Holland's Mental Physiology . 11
“ Medical Notes and Reflections 11
Kesteven's Domestic Medicine . 13
Pereira's Materia Medica . 18
Richardson's Cold-water Cure . 19
Spencer's Principles of Psychology . 21
Todd's Cyclopædia of Anatomy and Physiology . 22

Miscellaneous Literature.

Bacon's (Lord) Works . 5
Defence of *Eclipse of Faith* . 9
De Fonblanque on Army Administration 9
Eclipse of Faith . 9
Greathed's Letters from Delhi . 10
Greyson's Select Correspondence . 10
Gurney's Evening Recreations . 10
Hassall's Adulterations Detected, &c. . 11
Haydn's Book of Dignities . 11
Holland's Mental Physiology . 11

Hooker's Kew Guide 11
Howitt's Rural Life of England 12
" Visits to Remarkable Places 12
Jameson's Commonplace-Book 13
Jeffrey's (Lord) Essays 13
Last of the Old Squires 18
Letters of a Betrothed 13
Macaulay's Critical and Hist. Essays 14
" Speeches 14
Mackintosh's Miscellaneous Works 15
Martineau's Miscellanies 15
Pycroft's English Reading 19
Rich's Companion to Latin Dictionary 19
Riddle's Latin Dictionaries 19
Rowton's Debater 20
Sir Roger De Coverley 21
Smith's (Rev. Sydney) Works 21
Southey's Doctor, &c. 21
Spencer's Essays 21
Stephen's Essays 22
Stow's Training System 22
Thomson's Laws of Thought 22
Trevelyan on the Native Languages of India 22
Yonge's English-Greek Lexicon 24
" Latin Gradus 24
Zumpt's Latin Grammar 24

Natural History in general.

Agassiz on Classification 5
Catlow's Popular Conchology 8
Ephemera's Book of the Salmon 9
Garratt's Marvels of Instinct 10
Gosse's Natural History of Jamaica 10
Kirby and Spence's Entomology 13
Lee's Elements of Natural History 13
Maunder's Natural History 16
Morris's Anecdotes in Natural History 17
Quatrefages' Rambles of a Naturalist 19
Stonehenge on the Dog 22
Turton's Shells of the British Islands 23
Van der Hoeven's Handbook of Zoology 23
Waterton's Essays on Natural History 24
Youatt's The Dog 24
" The Horse 24

One-Volume Encyclopædias and Dictionaries.

Blaine's Rural Sports 6
Brande's Science, Literature, and Art 6
Copland's Dictionary of Medicine 8
Cresy's Civil Engineering 8
Gwilt's Architecture 10
Johnston's Geographical Dictionary 13
Loudon's Agriculture 14
" Rural Architecture 14
" Gardening 14
" Plants 14
" Trees and Shrubs 14
M'Culloch's Geographical Dictionary 15
" Dictionary of Commerce 15
Murray's Encyclopædia of Geography 17
Sharp's British Gazetteer 21
Ure's Dictionary of Arts, &c. 23
Webster's Domestic Economy 24

Religious and Moral Works.

Afternoon of Life 5
Amy Herbert 20
Bloomfield's Greek Testament 6
Bunyan's Pilgrim's Progress 7
Calvert's Wife's Manual 8
Catz and Farlie's Moral Emblems 8
Cleve Hall 20
Conybeare and Howson's St. Paul 8
Cotton's Instructions in Christianity 8
Dale's Domestic Liturgy 9
Defence of *Eclipse of Faith* 9
Earl's Daughter (The) 20
Eclipse of Faith 9
Englishman's Greek Concordance 9
" Heb. & Chald. Concord. 9
Experience (The) of Life 20
Gertrude 20
Harrison's Light of the Forge 10
Horne's Introduction to Scriptures 11
" Abridgment of ditto 11
Huc's Christianity in China 12
Humphreys's *Parables* Illuminated 12
Ivors, by the Author of *Amy Herbert* 20
Jameson's Saints and Martyrs 13
" Monastic Legends 13
" Legends of the Madonna 13
" on Female Employment 12
Jeremy Taylor's Works 13
Katharine Ashton 20
König's Pictorial Life of Luther 10
Laneton Parsonage 20
Letters to my Unknown Friends 13
Lyra Germanica 7
Maguire's Rome 15
Margaret Percival 20
Marshman's Serampore Mission 15
Martineau's Christian Life 15
" Hymns 15
" Studies of Christianity 15
Merivale's Christian Records 16
Milner's Church of Christ 16
Moore on the Use of the Body 17
" " Soul and Body 16
" 's Man and his Motives 17
Morning Clouds 17
Neale's Closing Scene 17
Pattison's Earth and Word 18
Powell's Christianity without Judaism 19
" Order of Nature 19
Readings for Lent 20
" Confirmation 20
Robinson's Lexicon to the Greek Testament 19
Self-Examination for Confirmation 20
Sewell's History of the Early Church 20
Sinclair's Journey of Life 21
Smith's (Sydney) Moral Philosophy 21
" (G.) Wesleyan Methodism 21
" (J.) Shipwreck of St. Paul 21
Southey's Life of Wesley 21
Stephen's Ecclesiastical Biography 22
Taylor's Loyola 22
" Wesley 22
Theologia Germanica 7
Thumb Bible (The) 22
Young's Christ of History 24
" Mystery 24

Poetry and the Drama.

Aikin's (Dr.) British Poets 5
Arnold's Merope 5
" Poems 5
Baillie's (Joanna) Poetical Works 5
Calvert's Wife's Manual 8
Goldsmith's Poems, illustrated 10
L. E. L.'s Poetical Works 14
Linwood's Anthologia Oxoniensis 14

Lyra Germanica 7
Macaulay's Lays of Ancient Rome . 15
MacDonald's Within and Without . 15
" Poems 15
Montgomery's Poetical Works . . 16
Moore's Poetical Works 17
" Selections (illustrated) . . 17
" Lalla Rookh 17
" Irish Melodies 17
" National Melodies . . . 17
" Sacred Songs (*with Music*) . 17
" Songs and Ballads . . . 17
Shakspeare, by Bowdler 20
Southey's Poetical Works . . . 21
Thomson's Seasons, illustrated . . 22

The Sciences in general and Mathematics.

Arago's Meteorological Essays . . 5
" Popular Astronomy . . . 5
Bourne on the Steam Engine . . 6
" 's Catechism of Steam-Engine . 6
Boyd's Naval Cadet's Manual . . 6
Brande's Dictionary of Science, &c. . 6
" Lectures on Organic Chemistry 6
Conington's Chemical Analysis . . 8
Cresy's Civil Engineering . . . 8
De la Rive's Electricity 9
Grove's Correlation of Physical Forces . 10
Herschel's Outlines of Astronomy . . 11
Holland's Mental Physiology . . . 11
Humboldt's Aspects of Nature . . 12
" Cosmos 12
Hunt on Light 12
Lardner's Cabinet Cyclopædia . . 13
Marcet's (Mrs.) Conversations . . 15
Morell's Elements of Psychology . . 17
Moseley's Engineering and Architecture 17
Ogilvie's Master-Builder's Plan . . 18
Owen's Lectures on Comp. Anatomy . 18
Pereira on Polarised Light . . . 18
Peschel's Elements of Physics . . 18
Phillips's Mineralogy 18
" Guide to Geology . . . 18
Powell's Unity of Worlds . . . 19
" Christianity without Judaism 19
" Order of Nature . . . 19
Smee's Electro-Metallurgy . . . 21
Steam-Engine, by the Artisan Club . 6
Webb's Celestial Objects for Common Telescopes 24

Rural Sports.

Baker's Rifle and Hound in Ceylon . 5
Blaine's Dictionary of Sports . . . 6
Cecil's Stable Practice 8
" Stud Farm 8
Davy's Fishing Excursions, 2 Series . 9
Ephemera on Angling 9
" Book of the Salmon . . 9
Freeman and Salvin's Falconry . . 10
Hawker's Young Sportsman . . . 11
The Hunting-Field 11
Idle's Hints on Shooting . . . 12
Pocket and the Stud 11
Practical Horsemanship 11
Pycroft's Cricket-Field 19
Richardson's Horsemanship . . . 19
Ronalds's Fly-Fisher's Entomology . 20
Stable Talk and Table Talk . . . 10
Stonehenge on the Dog . . . 22
" " Greyhound . . 22
The Stud, for Practical Purposes . . 11

Veterinary Medicine, &c.

Cecil's Stable Practice 8
" Stud Farm 8
Hunt's Horse and his Master . . 12
Hunting-Field (The) 11
Miles's Horse-Shoeing 16
" on the Horse's Foot . . . 16
Pocket and the Stud 11
Practical Horsemanship 11
Richardson's Horsemanship . . . 19
Stable Talk and Table Talk . . . 10
Stonehenge on the Dog 22
Stud (The) 11
Youatt's The Dog 24
" The Horse 24

Voyages and Travels.

Baker's Wanderings in Ceylon . . 5
Barth's African Travels 5
Burton's East Africa 7
" Medina and Mecca . . . 7
Domenech's Deserts of North America 9
" Texas and Mexico . . 9
First Impressions of the New World . 9
Forester's Sardinia and Corsica . . 10
Hinchliff's Travels in the Alps . . 11
Howitt's Art-Student in Munich . . 12
" (W.) Victoria 12
Huc's Chinese Empire 12
Hudson and Kennedy's Mont Blanc . 12
Humboldt's Aspects of Nature . . 12
Hutchinson's Western Africa . . 12
Kane's Wanderings of an Artist . . 13
Lady's Tour round Monte Rosa . . 13
M'Clure's North West Passage . . 18
Mac Dougall's Voyage of the *Resolute* . 15
Minturn's New York to Delhi . . 16
Möllhausen's Journey to the Pacific . 16
Osborn's Quedah 18
Peaks, Passes, and Glaciers . . . 18
Scherzer's Central America . . . 20
Senior's Journal in Turkey and Greece 20
Snow's Tierra del Fuego 21
Tennent's Ceylon 22
Von Tempsky's Mexico and Guatemala 23
Wanderings in the Land of Ham . . 24
Weld's Vacations in Ireland . . . 24
" Pyrenees, West and East . . 24
" United States and Canada . . 24

Works of Fiction.

Connolly's Romance of the Ranks . 8
Cruikshank's Falstaff 9
Howitt's Tallangetta 12
Mildred Norman 16
Moore's Epicurean 17
Sewell's Ursula 20
Sir Roger De Coverley 21
Sketches (The), Three Tales . . . 21
Southey's Doctor, &c. 21
Trollope's Barchester Towers . . . 23
" Warden 23

ALPHABETICAL CATALOGUE

of

NEW WORKS and NEW EDITIONS

PUBLISHED BY

LONGMAN, GREEN, LONGMAN, AND ROBERTS,

PATERNOSTER ROW, LONDON.

Miss Acton's Modern Cookery for Private Families, reduced to a System of Easy Practice in a Series of carefully-tested Receipts, in which the Principles of Baron Liebig and other eminent writers have been as much as possible applied and explained. Newly-revised and enlarged Edition; with 8 Plates, comprising 27 Figures, and 150 Woodcuts. Fcp. 8vo. 7s. 6d.

Acton's English Bread-Book for Domestic Use, adapted to Families of every grade. Fcp. 8vo. price 4s. 6d.

The Afternoon of Life. By the Author of *Morning Clouds*. New and cheaper Edition, thoroughly revised. Fcp. 8vo. 5s.

Agassiz. — An Essay on Classification. By LOUIS AGASSIZ. 8vo. 12s.

Aikin's Select Works of the British Poets from Ben Jonson to Beattie. New Edition; with Biographical and Critical Prefaces, and Selections from recent Poets. 8vo. 18s.

Arago (F.)—Biographies of Distinguished Scientific Men. Translated by Admiral W. H. SMYTH, D.C.L., F.R.S., &c.; the Rev. BADEN POWELL, M.A.; and ROBERT GRANT, M.A., F.R.A.S. 8vo. 18s.

Arago's Meteorological Essays. With an Introduction by BARON HUMBOLDT. Translated under the superintendence of Lieut.-Col. E. SABINE, R.A., Treasurer and V.P.R.S. 8vo. 18s.

Arago's Popular Astronomy. Translated and edited by Admiral W. H. SMYTH, D.C.L., F.R.S.; and ROBERT GRANT, M.A., F.R.A.S. With 25 Plates and 358 Woodcuts. 2 vols. 8vo. price £2. 5s.

Arnold. — Merope, a Tragedy. By MATTHEW ARNOLD. With a Preface and an Historical Introduction. Fcp. 8vo. 5s.

Arnold.—Poems. By Matthew ARNOLD. FIRST SERIES, Third Edition. Fcp. 8vo. 5s. 6d. SECOND SERIES, price 5s.

Lord Bacon's Works. A New Edition, collected and edited by R. L. ELLIS, M.A., Fellow of Trinity College, Cambridge; J. SPEDDING, M.A. of Trinity College, Cambridge; and D. D. HEATH, Esq., Barrister-at-Law, and late Fellow of Trinity College, Cambridge. VOLS. I. to V. comprising the Division of *Philosophical Works*; with a copious INDEX. 5 vols. 8vo. price £4. 6s. VOL. VI. price 18s.

VOL VII., completing the Division of *Literary and Professional Works*, is just ready.

Joanna Baillie's Dramatic and Poetical Works: Comprising Plays of the Passions, Miscellaneous Dramas, Metrical Legends, Fugitive Pieces, and Ahalya Baee; with the Life of Joanna Baillie, Portrait and Vignette. Square crown 8vo. 21s. cloth; or 42s. morocco.

Baker.—The Rifle and the Hound in Ceylon. By S. W. BAKER, Esq. New Edition, with 13 Illustrations engraved on Wood. Fcp. 8vo. 4s. 6d.

Baker. — Eight Years' Wanderings in Ceylon. By S. W. BAKER, Esq. With 6 coloured Plates. 8vo. 15s.

Barth.—Travels and Discoveries in North and Central Africa: Being the Journal of an Expedition undertaken under the auspices of Her Britannic Majesty's Government in the Years 1849—1855. By HENRY BARTH, Ph.D., D.C.L., &c. With numerous Maps and Illustrations. 5 vols. 8vo. £5. 5s. cloth.

Bate. — Memoir of Captain W. Thornton Bate, R.N. By the Rev. John Baillie, Author of "Memoirs of Hewitson," "Memoir of Adelaide Newton," &c. *New Edition;* with Portrait and 4 Illustrations. Fcp. 8vo. price 5s.

Baylдon's Art of Valuing Rents and Tillages, and Claims of Tenants upon Quitting Farms, at both Michaelmas and Lady-day; as revised by Mr. Donaldson. *Seventh Edition*, enlarged and adapted to the Present Time. By Robert Baker, Land-Agent and Valuer. 8vo. price 10s. 6d.

Bayldon's (R.) Treatise on Road Legislation and Management; with Remarks on Tolls, and on Repairing Turnpike-Roads and Highways. 8vo. price 3s. 6d.

Black's Practical Treatise on Brewing, based on Chemical and Economical Principles: With Formulæ for Public Brewers, and Instructions for Private Families. 8vo. 10s. 6d.

Blaine's Encyclopædia of Rural Sports; or, a complete Account, Historical, Practical, and Descriptive, of Hunting, Shooting, Fishing, Racing, &c. *New Edition*, revised and corrected to the Present Time; with above 600 Woodcut Illustrations, including 20 Subjects now added from Designs by John Leech. In One Volume, 8vo. price 42s. half-bound.

Bloomfield.—The Greek Testament: with copious English Notes, Critical, Philological, and Explanatory. Especially adapted to the use of Theological Students and Ministers. By the Rev. S. T. Bloomfield, D.D., F.S.A. Ninth Edition, revised. 2 vols. 8vo. with Map, £2. 8s.

Dr. Bloomfield's College & School Edition of the Greek Testament: With brief English Notes, chiefly Philological and Explanatory. Seventh Edition; with Map and Index. Fcp. 8vo. 7s. 6d.

Dr. Bloomfield's College & School Lexicon to the Greek Testament. New Edition, revised. Fcp. 8vo. price 10s. 6d.

Boyd. — A Manual for Naval Cadets. Published with the sanction and approval of the Lords Commissioners of the Admiralty. By John M'Neill Boyd, Captain, R.N. With Compass-Signals in Colours, and 236 Woodcuts. Fcp. 8vo. 10s. 6d.

Bourne. — A Treatise on the Steam Engine, in its Application to Mines, Mills, Steam Navigation, and Railways. By the Artisan Club. Edited by John Bourne, C.E. New Edition; with 33 Steel Plates, and 349 Wood Engravings. 4to. 27s.

Bourne's Catechism of the Steam Engine in its various Applications to Mines, Mills, Steam Navigation, Railways, and Agriculture: With Practical Instructions for the Manufacture and Management of Engines of every class. Fourth Edition, enlarged; with 89 Woodcuts. Fcp. 8vo. 6s.

Brande's Dictionary of Science, Literature, and Art; comprising the History, Description, and Scientific Principles of every Branch of Human Knowledge; with the Derivation and Definition of all the Terms in general use. Third Edition, revised and corrected; with numerous Woodcuts. 8vo. 60s.

Professor Brande's Lectures on Organic Chemistry, as applied to Manufactures, including Dyeing, Bleaching, Calico Printing, Sugar Manufacture, the Preservation of Wood, Tanning, &c. Edited by J. Scoffern, M.B. Fcp. Woodcuts, 7s. 6d.

Brewer.—An Atlas of History and Geography, from the Commencement of the Christian Era to the Present Time: Comprising a Series of Sixteen Coloured Maps, arranged in Chronological Order, with Illustrative Memoirs. By the Rev. J. S. Brewer, M.A. *Second Edition*, revised and corrected. Royal 8vo. 12s. 6d. half-bound.

Brialmont. — The Life of the Duke of Wellington. From the French of Alexis Brialmont, Captain on the Staff of the Belgian Army: With Emendations and Additions. By the Rev. G. R. Gleig, M.A., Chaplain-General to the Forces and Prebendary of St. Paul's. With Maps, Plans, and Portraits. Vols. I. and II. 8vo. price 30s.

The Third and Fourth Volumes (completion) are now in the press, and will take up the history of the Duke from the Battle of Waterloo, representing him as an Ambassador, as a Minister, and as a Citizen.

Brodie. — Psychological Inquiries, in a Series of Essays intended to illustrate the Influence of the Physical Organisation on the Mental Faculties. By Sir Benjamin C. Brodie, Bart. Third Edition. Fcp. 8vo. 5s.

Dr. Bull on the Maternal Management of Children in Health and Disease. New Edition. Fcp. 8vo. 5s.

Dr. Bull's Hints to Mothers on the Management of their Health during the Period of Pregnancy and in the Lying-in Room: With an Exposure of Popular Errors in connexion with those subjects, &c.; and Hints upon Nursing. New Edition. Fcp. 8vo. 5s.

Dr. Bull's Work on Blindness, entitled the Sense of Vision Denied and Lost. Edited by the Rev. B. G. Johns, Chaplain of the Blind School, St. George's Fields. With a brief introductory Memoir of the Author by Mrs. Bull. Fcp. 8vo. 4s. 6d.

Bunsen.—Christianity and Mankind, their Beginnings and Prospects. By Baron C. C. J. Bunsen, D.D., D.C.L., D.Ph. Being a New Edition, corrected, re-modelled, and extended, of *Hippolytus and his Age.* 7 vols. 8vo. £5. 5s.

*** This Edition is composed of three distinct works, as follows:—

1. Hippolytus and his Age; or, the Beginnings and Prospects of Christianity. 2 vols. 8vo. £1. 10s.
2. Outline of the Philosophy of Universal History applied to Language and Religion; containing an Account of the Alphabetical Conferences. 2 vols. 33s.
3. Analecta Ante-Nicæna. 3 vols. 8vo. £2. 2s.

Bunsen. — Lyra Germanica. Translated from the German by Catherine Winkworth. *Fifth Edition* of the First Series, Hymns for the Sundays and Festivals of the Christian Year. *New Edition* of the Second Series, the Christian Life. Fcp. 8vo. 5s. each Series.

HYMNS from *Lyra Germanica*, 18mo. 1s.

*** These selections of German Hymns have been made from collections published in Germany by Baron Bunsen; and form companion volumes to

Theologia Germanica: Which setteth forth many fair lineaments of Divine Truth, and saith very lofty and lovely things touching a Perfect Life. Translated by Susanna Winkworth. With a Preface by the Rev. Charles Kingsley; and a Letter by Baron Bunsen. Third Edition. Fcp. 8vo. 5s.

Bunsen.—Egypt's Place in Universal History: An Historical Investigation, in Five Books. By Baron C. C. J. Bunsen, D.C.L., D.Ph. Translated from the German by C. H. Cottrell, Esq., M.A. With many Illustrations. Vol. I. 8vo. 28s.; Vol. II. price 30s.; and Vol. III. price 25s.

Bunting. — The Life of Jabez Bunting, D.D.: With Notices of contemporary Persons and Events. By his Son, Thomas Percival Bunting. Vol. I. with Two Portraits and a Vignette, in post 8vo. 7s. 6d.: or *(large paper and Proof Engravings)* in square crown 8vo. 10s. 6d.

Bunyan's Pilgrim's Progress: With a Preface by the Rev. Charles Kingsley, Rector of Eversley; and a Series of 126 Illustrations engraved on Steel and on Wood from Original Designs by Charles Bennett. Fcp. 4to. price 21s. cloth, gilt edges.

Burton.—First Footsteps in East Africa; or, an Exploration of Harar. By Richard F. Burton, Captain, Bombay Army. With Maps and coloured Plate. 8vo. 18s.

Burton.—Personal Narrative of a Pilgrimage to El Medinah and Meccah. By Richard F. Burton, Captain, Bombay Army. *Second Edition,* revised; with coloured Plates and Woodcuts. 2 vols. crown 8vo. 24s.

Bishop Butler's Sketch of Modern and Ancient Geography. New Edition, thoroughly revised, with such Alterations introduced as continually progressive Discoveries and the latest information have rendered necessary. Post 8vo. 7s. 6d.

Bishop Butler's General Atlas of Modern and Ancient Geography; comprising Fifty-two full-coloured Maps; with complete Indices. New Edition, enlarged, and greatly improved. Edited by the Author's Son. Royal 4to. 24s.

The Cabinet Lawyer: A Popular Digest of the Laws of England, Civil and Criminal; with a Dictionary of Law Terms, Maxims, Statutes, and Judicial Antiquities; Correct Tables of Assessed Taxes, Stamp Duties, Excise Licenses, and Post-Horse Duties; Post-Office Regulations; and Prison Discipline. 18th Edition, comprising the Public Acts of the Session 1858. Fcp. 8vo. 10s. 6d.

The Cabinet Gazetteer: A Popular Exposition of All the Countries of the World. By the Author of *The Cabinet Lawyer*. Fcp. 8vo. 10s. 6d.

Caird. — Prairie Farming in America: With Notes by the way on Canada and the United States. By JAMES CAIRD, M.P., Author of "English Agriculture," "High Farming," &c. 16mo. 3s. 6d.

Calvert. — The Wife's Manual; or, Prayers, Thoughts, and Songs on Several Occasions of a Matron's Life. By the Rev. W. CALVERT, M.A. Ornamented from Designs by the Author in the style of *Queen Elizabeth's Prayer-Book*. Crown 8vo. 10s. 6d.

Catlow's Popular Conchology; or, the Shell Cabinet arranged according to the Modern System: With a detailed Account of the Animals, and a complete Descriptive List of the Families and Genera of Recent and Fossil Shells. Second Edition, improved; with 405 Woodcuts. Post 8vo. 14s.

Catz and Farlie's Book of Emblems.—Moral Emblems from JACOB CATZ and ROBERT FARLIE; with Aphorisms, Adages, and Proverbs of all Nations. The Illustrations freely rendered from designs found in the works of Catz and Farlie, by JOHN LEIGHTON, F.S.A., and engraved under his superintendence. Imperial 8vo. with 60 large Illustrations on Wood, and numerous Vignettes and Tail Pieces.

Cecil. — The Stud Farm; or, Hints on Breeding Horses for the Turf, the Chase, and the Road. Addressed to Breeders of Race-Horses and Hunters, Landed Proprietors, and Tenant Farmers. By CECIL. Fcp. 8vo. 5s.

Cecil's Stable Practice; or, Hints on Training for the Turf, the Chase, and the Road; with Observations on Racing and Hunting, Wasting, Race-Riding, and Handicapping: Addressed to all who are concerned in Racing, Steeple-Chasing, and Fox-Hunting. Second Edition. Fcp. 8vo. with Plate, 5s.

Chapman.—History of Gustavus Adolphus, and of the Thirty Years' War up to the King's Death: With some Account of its Conclusion by the Peace of Westphalia, in 1648. By B. CHAPMAN, M.A. 8vo. Plans, 12s. 6d.

Conington.—Handbook of Chemical Analysis, adapted to the Unitary System of Notation. By F. T. CONINGTON, M.A., F.C.S. Post 8vo. 7s. 6d. Also, *Tables of Qualitative Analysis*, designed as a Companion to the Handbook. Price 2s. 6d.

Connolly.—The Romance of the Ranks; or, Anecdotes, Episodes, and Social Incidents of Military Life. By T. W. J. CONNOLLY, Quartermaster of the Royal Engineers. 2 vols. 8vo. 21s.

Connolly's History of the Royal Sappers and Miners: Including the Services of the Corps in the Crimea and at the Siege of Sebastopol. *Second Edition*; with 17 coloured Plates. 2 vols. 8vo. 30s.

Conybeare and Howson's Life and Epistles of Saint Paul: Comprising a complete Biography of the Apostle, and a Translation of his Epistles inserted in Chronological Order. *Third Edition*, revised and corrected; with several Maps and Woodcuts, and 4 Plates. 2 vols. square crown 8vo. 31s. 6d.

⁂ The Original Edition, with more numerous Illustrations, in 2 vols. 4to. price 48s.—may also be had.

Dr. Copland's Dictionary of Practical Medicine: Comprising General Pathology, the Nature and Treatment of Diseases, Morbid Structures, and the Disorders especially incidental to Climates, to Sex, and to the different Epochs of Life; with numerous approved Formulæ of the Medicines recommended. Now complete in 3 vols. 8vo. price £5. 11s. cloth.

Bishop Cotton's Instructions in the Doctrine and Practice of Christianity. Intended as an Introduction to Confirmation. 4th Edition. 18mo. 2s. 6d.

Cresy's Encyclopædia of Civil Engineering, Historical, Theoretical, and Practical. Illustrated by upwards of 3,000 Woodcuts. *Second Edition*, revised; and extended in a Supplement, comprising Metropolitan Water-Supply, Drainage of Towns, Railways, Cubical Proportion, Brick and Iron Construction, Iron Screw Piles, Tubular Bridges, &c. 8vo. 63s.

Crosse. — Memorials, Scientific and Literary, of Andrew Crosse, the Electrician. Edited by Mrs. CROSSE. Post 8vo. 9s. 6d.

Crowe.—The History of France. By Eyre Evans Crowe. In Five Volumes. Vol. I. 8vo. 14s.

Cruikshank. — The Life of Sir John Falstaff, illustrated in a Series of Twenty-four original Etchings by George Cruikshank. Accompanied by an imaginary Biography of the Knight, by Robert B. Brough. Royal 8vo. price 12s. 6d. cloth.

Lady Cust's Invalid's Own Book: A Collection of Recipes from various Books and various Countries. *Second Edition.* Fcp. 8vo. 2s. 6d.

The Rev. Canon Dale's Domestic Liturgy and Family Chaplain, in Two Parts: Part I. Church Services adapted for Domestic Use, with Prayers for Every Day of the Week, selected from the Book of Common Prayer; Part II. an appropriate Sermon for Every Sunday in the Year. Second Edition. Post 4to. 21s. cloth; 31s. 6d. calf; or £2. 10s. morocco.

Separately { The Family Chaplain, 12*s.*
The Domestic Liturgy, 10*s.* 6*d.*

Davy (Dr. J.)—The Angler and his Friend; or, Piscatory Colloquies and Fishing Excursions. By John Davy, M.D., F.R.S., &c. Fcp. 8vo. 6s.

By the same Author,

The Angler in the Lake District; or, Piscatory Colloquies and Fishing Excursions in Westmoreland and Cumberland. Fcp. 8vo. 6s. 6d.

De Fonblanque.—The Administration and Organisation of the British Army, with especial reference to Finance and Supply. By Edward Barrington De Fonblanque, Assistant Commissary-General. 8vo. 12s.

De la Rive's Treatise on Electricity in Theory and Practice. Translated for the Author by C. V. Walker, F.R.S. 3 vols. 8vo. Woodcuts, £3. 13s.

Domenech.—Seven Years' Residence in the Great Deserts of North America. By the Abbé Domenech. With a Map, and about Sixty Woodcut Illustrations. 2 vols. 8vo. [*Just ready.*

Abbé Domenech's Missionary Adventures in Texas and Mexico: A Personal Narrative of Six Years' Sojourn in those Regions. 8vo. 10s. 6d.

The Eclipse of Faith; or, a Visit to a Religious Sceptic. *9th Edition.* Fcp. 8vo. 5s.

Defence of The Eclipse of Faith, by its Author: Being a Rejoinder to Professor Newman's *Reply:* Including a full Examination of that Writer's Criticism on the Character of Christ; and a Chapter on the Aspects and Pretensions of Modern Deism. *Second Edition,* revised. Post 8vo. 5s. 6d.

The Englishman's Greek Concordance of the New Testament: Being an Attempt at a Verbal Connexion between the Greek and the English Texts; including a Concordance to the Proper Names, with Indexes, Greek-English and English-Greek. New Edition, with a new Index. Royal 8vo. 42s.

The Englishman's Hebrew and Chaldee Concordance of the Old Testament: Being an Attempt at a Verbal Connexion between the Original and the English Translations; with Indexes, a List of the Proper Names and their Occurrences, &c. 2 vols. royal 8vo. £3. 13s. 6d.; large paper, £4. 14s. 6d.

Ephemera's Handbook of Angling; teaching Fly-fishing, Trolling, Bottom-Fishing, Salmon-Fishing: With the Natural History of River-Fish, and the best Modes of Catching them. Third Edition, corrected and improved; with Woodcuts. Fcp. 8vo. 5s.

Ephemera's Book of the Salmon: The Theory, Principles, and Practice of Fly-Fishing for Salmon; Lists of good Salmon Flies for every good River in the Empire; the Natural History of the Salmon, its Habits described, and the best way of artificially Breeding it. Fcp. 8vo. with coloured Plates, 14s.

Fairbairn.—Useful Information for Engineers: Being a Series of Lectures delivered to the Working Engineers of Yorkshire and Lancashire. By William Fairbairn, F.R.S., F.G.S. *Second Edition;* with Plates and Woodcuts. Crown 8vo. 10s. 6d.

First Impressions of the New World on Two Travellers from the Old in the Autumn of 1858. With Map by Arrowsmith. Post 8vo. 8s. 6d.

Fischer. — Francis Bacon of Verulam: Realistic Philosophy and its Age. By Dr. K. Fischer. Translated by J. Oxenford. Post 8vo. 9s. 6d.

Forester. — Rambles in the Islands of Corsica and Sardinia: With Notices of their History, Antiquities, and present Condition. By THOMAS FORESTER. With coloured Map; and numerous Lithographic and Woodcut Illustrations from Drawings made during the Tour by Lieut.-Col. M. A. Biddulph, R.A. Imperial 8vo. 28s.

Frazer. — Letters of Sir A. S. Frazer, K.C.B. Commanding the Royal Horse Artillery under the Duke of Wellington: Written during the Peninsular and Waterloo Campaigns. Edited by MAJOR-GENERAL SABINE, R.A. With Portrait, 2 Maps, and Plans. 8vo. 18s.

Freeman and Salvin.—Falconry: Its Claims, History, and Practice. By GAGE EARLE FREEMAN, M.A. ("Peregrine" of the *Field* newspaper); and Captain F. H. SALVIN. Post 8vo. with Woodcut Illustrations from Drawings by Wolf, price 10s. 6d. cloth.

Garratt.—Marvels and Mysteries of Instinct; or, Curiosities of Animal Life. By GEORGE GARRATT. *Second Edition*, improved. Fcp. 8vo. 4s. 6d.

Gilbart.—A Practical Treatise on Banking. By JAMES WILLIAM GILBART, F.R.S. *Sixth Edition.* 2 vols. 12mo. 16s.

Gilbart's Logic of Banking: A Familiar Exposition of the Principles of Reasoning, and their Application to the Art and the Science of Banking. 12mo. with Portrait, 12s. 6d.

Gleig. — Essays, Biographical, Historical, and Miscellaneous, contributed chiefly to the *Edinburgh* and *Quarterly Reviews*. By the Rev. G. R. GLEIG, M.A., Chaplain-General to the Forces, and Prebendary of St. Paul's. 2 vols. 8vo. price 21s.

The Poetical Works of Oliver Goldsmith. Edited by BOLTON CORNEY, Esq. Illustrated by Wood Engravings, from Designs by Members of the Etching Club. Square crown 8vo. cloth, 21s.; morocco, £1. 16s.

Gosse.—A Naturalist's Sojourn in Jamaica. By P. H. GOSSE, Esq. With Plates. Post 8vo. 14s.

Greathed.—Letters from Delhi written during the Siege. By H. H. GREATHED, late of the Bengal Civil Service. Edited by his Widow. Post 8vo. 8s. 6d.

Green.—Lives of the Princesses of England. By Mrs. MARY ANNE EVERETT GREEN, Editor of the *Letters of Royal and Illustrious Ladies*. With numerous Portraits. Complete in 6 vols. post 8vo. 10s. 6d. each.

Greyson.—Selections from the Correspondence of R. E. GREYSON, Esq. Edited by the Author of *The Eclipse of Faith*. New Edition. Crown 8vo. 7s. 6d.

Grove.—The Correlation of Physical Forces. By W. R. GROVE, Q.C., M.A. *Third Edition.* 8vo. 7s.

Gurney.—St. Louis and Henri IV.: Being a Second Series of Historical Sketches. By the Rev. JOHN H. GURNEY, M.A. Fcp. 8vo. 6s.

Evening Recreations; or, Samples from the Lecture-Room. Edited by Rev. J. H. GURNEY. Crown 8vo. 5s.

Gwilt's Encyclopædia of Architecture, Historical, Theoretical, and Practical. By JOSEPH GWILT. With more than 1,000 Wood Engravings, from Designs by J. S. GWILT. 8vo. 42s.

Hare (Archdeacon).—The Life of Luther, in Forty-eight Historical Engravings. By GUSTAV KÖNIG. With Explanations by Archdeacon HARE and SUSANNAH WINKWORTH. Fcp. 4to. 28s.

Harford.—Life of Michael Angelo Buonarroti: With Translations of many of his Poems and Letters; also Memoirs of Savonarola, Raphael, and Vittoria Colonna. By JOHN S. HARFORD, Esq., D.C.L., F.R.S. Second Edition, revised; with 20 Plates. 2 vols. 8vo. 25s.

Illustrations, Architectural and Pictorical, of the Genius of Michael Angelo Buonarroti. With Descriptions of the Plates, by the Commendatore CANINA; C. R. COCKERELL, Esq., R.A.; and J. S. HARFORD, Esq., D.C.L., F.R.S. Folio, 73s. 6d. half-bound.

Harrison. — The Light of the Forge; or, Counsels from the Sick-Bed of E. M. By the Rev. W. HARRISON, M.A., Domestic Chaplain to the Duchess of Cambridge. Fcp. 8vo. 5s.

Harry Hieover's Stable Talk and Table Talk; or, Spectacles for Young Sportsmen. New Edition, 2 vols. 8vo. Portrait, 24s.

Harry Hieover.—The Hunting-Field. By HARRY HIEOVER. With Two Plates. Fcp. 8vo. 5s. half-bound.

Harry Hieover. — Practical Horsemanship. *Second Edition;* with 2 Plates. Fcp. 8vo. 5s. half-bound.

Harry Hieover.—The Pocket and the Stud; or, Practical Hints on the Management of the Stable. By HARRY HIEOVER. Fcp. 8vo. Portrait, 5s.

Harry Hieover.—The Stud, for Practical Purposes and Practical Men: Being a Guide to the Choice of a Horse for use more than for show. Fcp. 5s.

Hassall.—A History of the British Freshwater Algæ: Including Descriptions of the Desmideæ and Diatomaceæ. By ARTHUR HILL HASSALL, M.D. 2 vols. 8vo. with 10 Plates, £1. 15s.

Hassall.—Adulterations Detected; or, Plain Instructions for the Discovery of Frauds in Food and Medicine. By ARTHUR HILL HASSALL, M.D. Lond., Analyst of *The Lancet* Sanitary Commission, and Author of the Reports of that Commission published under the title of *Food and its Adulterations* (which may also be had, in 8vo. price 28s.) With 225 Illustrations, engraved on Wood. Crown 8vo. 17s. 6d.

Col. Hawker's Instructions to Young Sportsmen in all that relates to Guns and Shooting. 11th Edition, revised by the Author's Son, Major P. W. L. HAWKER. With Portrait, Plates, and Woodcuts. Sq. crown 8vo. 18s.

Haydn's Book of Dignities: Containing Rolls of the Official Personages of the British Empire, Civil, Ecclesiastical, Judicial, Military, Naval, and Municipal, from the Earliest Periods to the Present Time. Together with the Sovereigns of Europe, from the Foundation of their respective States; the Peerage and Nobility of Great Britain, &c. 8vo. 25s.

Hayward. — Biographical and Critical Essays, reprinted from Reviews, with Additions and Corrections. By A. HAYWARD, Esq., Q.C. 2 vols. 8vo. 24s.

Sir John Herschel's Outlines of Astronomy. Fifth Edition, revised and corrected to the existing state of astronomical knowledge; with Plates and Woodcuts. 8vo. 18s.

Sir John Herschel's Essays from the *Edinburgh* and *Quarterly Reviews,* with Addresses and other Pieces. 8vo. 18s.

Hinchliff. — Summer Months among the Alps: With the Ascent of Monte Rosa. By THOS. W. HINCHLIFF, Barrister-at-Law. Post 8vo. 10s. 6d.

Hints on Etiquette and the Usages of Society: With a Glance at Bad Habits. New Edition, revised (with Additions) by a Lady of Rank. Fcp. 8vo. 2s. 6d.

Holland.—Medical Notes and Reflections. By Sir HENRY HOLLAND, M.D., F.R.S., &c., Physician in Ordinary to the Queen and Prince-Consort. Third Edition. 8vo. 18s.

Sir H. Holland's Chapters on Mental Physiology, founded chiefly on Chapters contained in *Medical Notes and Reflections.* Post 8vo. 8s. 6d.

Hooker.—Kew Gardens; or, a Popular Guide to the Royal Botanic Gardens of Kew. By Sir WILLIAM JACKSON HOOKER, K.H., &c., Director. With many Woodcuts. 16mo. 6d.

Hooker and Arnott's British Flora; comprising the Phænogamous or Flowering Plants, and the Ferns. Seventh Edition, with Additions and Corrections; and numerous Figures illustrative of the Umbelliferous Plants, the Composite Plants, the Grasses, and the Ferns. 12mo. with 12 Plates, 14s.; with the Plates coloured, 21s.

Horne's Introduction to the Critical Study and Knowledge of the Holy Scriptures. *Tenth Edition,* revised, corrected, and brought down to the present time. Edited by the Rev. T. HARTWELL HORNE, B.D. (the Author); the Rev. SAMUEL DAVIDSON, D.D. of the University of Halle, and LL.D.; and S. PRIDEAUX TREGELLES, LL.D. With 4 Maps and 22 Vignettes and Facsimiles. 4 vols. 8vo. £3. 13s. 6d.

Horne.—A Compendious Introduction to the Study of the Bible. By the Rev. T. HARTWELL HORNE, B.D. New Edition, with Maps, &c. 12mo. 9s.

Hoskyns.—Talpa; or, the Chronicles of a Clay Farm: An Agricultural Fragment. By CHANDOS WREN HOSKYNS, Esq. Fourth Edition. With 24 Woodcuts from Designs by GEORGE CRUIKSHANK. 16mo. 5s. 6d.

Howitt (A. M.)—An Art-Student in Munich. By Anna Mary Howitt. 2 vols. post 8vo. 14s.

Howitt.—The Children's Year. By Mary Howitt. With Four Illustrations. Square 16mo. 5s.

Howitt. — Tallangetta, the Squatter's Home: A Story of Australian Life. By William Howitt. 2 vols. post 8vo. 18s.

Howitt. — Land, Labour, and Gold; or, Two Years in Victoria: With Visit to Sydney and Van Diemen's Land. By William Howitt. Second Edition. 2 vols. crown 8vo. 10s.

W. Howitt's Visits to Remarkable Places: Old Halls, Battle-Fields, and Scenes illustrative of Striking Passages in English History and Poetry. With about 80 Wood Engravings. *New Edition.* 2 vols. square crown 8vo. 25s.

William Howitt's Boy's Country Book: Being the Real Life of a Country Boy, written by himself; exhibiting all the Amusements, Pleasures, and Pursuits of Children in the Country. With 40 Woodcuts. Fcp. 8vo. 6s.

William Howitt's Rural Life of England. With Woodcuts by Bewick and Williams. Medium 8vo. 21s.

The Abbé Huc's Work on the Chinese Empire, founded on Fourteen Years' Travel and Residence in China. People's Edition, with 2 Woodcut Illustrations. Crown 8vo. 5s.

Huc. — Christianity in China, Tartary, and Thibet. By M. l'Abbé Huc, formerly Missionary Apostolic in China. Vols. I. and II. 8vo. 21s.; and Vol. III 10s. 6d.

Hudson's Executor's Guide. New and improved Edition; with the Statutes enacted, and the Judicial Decisions pronounced since the last Edition incorporated. Fcp. 8vo. 6s.

Hudson's Plain Directions for Making Wills in conformity with the Law. New Edition, corrected and revised by the Author; and practically illustrated by Specimens of Wills containing many varieties of Bequests, also Notes of Cases judicially decided since the Wills Act came into operation. Fcp. 8vo. 2s. 6d.

Hudson and Kennedy's Ascent of Mont Blanc by a New Route and Without Guides. *Second Edition*, with Plate and Map. Post 8vo. 5s. 6d.

Humboldt's Cosmos. Translated, with the Author's authority, by Mrs. Sabine. Vols. I. and II. 16mo. Half-a-Crown each, sewed; 3s. 6d. each, cloth; or in post 8vo. 12s. each, cloth. Vol. III. post 8vo. 12s. 6d. cloth: or in 16mo. Part I. 2s. 6d. sewed, 3s. 6d. cloth; and Part II. 3s. sewed, 4s. cloth. Vol. IV. Part I. post 8vo. 15s. cloth; 16mo. 7s. 6d. cloth.

Humboldt's Aspects of Nature. Translated, with the Author's authority, by Mrs. Sabine. 16mo. price 6s.: or in 2 vols. 3s. 6d. each, cloth; 2s. 6d. each, sewed.

Humphreys.— Parables of Our Lord, illuminated and ornamented in the style of the Missals of the Renaissance by H. N. Humphreys. Square fcp. 8vo. 21s. in massive carved covers; or 30s. bound in morocco, by Hayday.

Hunt (Capt.).—The Horse and his Master: With Hints on Breeding, Breaking, Stable-Management, Training, Elementary Horsemanship, Riding to Hounds, &c. By Vere D. Hunt, Esq., late 109th Regt. Co. Dublin Militia. Fcp. 8vo. with Frontispiece, price 5s.

Hunt.—Researches on Light in its Chemical Relations; embracing a Consideration of all the Photographic Processes. By Robert Hunt, F.R.S. Second Edition, with Plate and Woodcuts. 8vo. 10s. 6d.

Hutchinson. — Impressions of Western Africa: With a Report on the Peculiarities of Trade up the Rivers in the Bight of Biafra. By J. T. Hutchinson, Esq., British Consul for the Bight of Biafra and the Island of Fernando Po. Post 8vo. 8s. 6d.

Idle.—Hints on Shooting, Fishing, &c., both on Sea and Land, and in the Fresh-Water Lochs of Scotland: Being the Experiences of C. Idle, Esq. Fcp. 8vo. 5s.

Mrs. Jameson's Two Lectures on the Social Employments of Women, *Sisters of Charity* and the *Communion of Labour.* New Edition, with a Prefatory Letter on the Present Condition and Requirements of the Women of England. Fcp. 8vo. 2s.

Mrs. Jameson's Legends of the Saints and Martyrs, as represented in Christian Art: Forming the FIRST SERIES of *Sacred and Legendary Art.* Third Edition; with 17 Etchings and upwards of 180 Woodcuts. 2 vols. square crown 8vo. 31s. 6d.

Mrs. Jameson's Legends of the Monastic Orders, as represented in Christian Art. Forming the SECOND SERIES of *Sacred and Legendary Art.* Second Edition, enlarged; with 11 Etchings by the Author and 88 Woodcuts. Square crown 8vo. 28s.

Mrs. Jameson's Legends of the Madonna, as represented in Christian Art: Forming the THIRD SERIES of *Sacred and Legendary Art.* Second Edition, corrected and enlarged; with 27 Etchings and 165 Wood Engravings. Square crown 8vo. 28s.

Mrs. Jameson's Commonplace-Book of Thoughts, Memories, and Fancies, Original and Selected. *Second Edition,* revised and corrected; with Etchings and Woodcuts. Crown 8vo. price 18s.

Jaquemet's Compendium of Chronology: Containing the most important Dates of General History, Political, Ecclesiastical, and Literary, from the Creation of the World to the end of the Year 1854. Post 8vo. 7s. 6d.

Jaquemet's Chronology for Schools: Containing the most important Dates of General History, Political, Ecclesiastical, and Literary, from the Creation of the World to the end of the Year 1857. Fcp. 8vo. 3s. 6d.

Lord Jeffrey's Contributions to The Edinburgh Review. A New Edition, complete in One Volume, with Portrait and Vignette. Square crown 8vo. 21s. cloth; or 30s. calf.—Or in 3 vols. 8vo. price 42s.

Bishop Jeremy Taylor's Entire Works: With Life by Bishop HEBER. Revised and corrected by the Rev. CHARLES PAGE EDEN, Fellow of Oriel College, Oxford. Now complete in 10 vols. 8vo. 10s. 6d. each.

Kane.—Wanderings of an Artist among the Indians of North America; from Canada to Vancouver's Island and Oregon, through the Hudson's Bay Company's Territory, and back again. By PAUL KANE. With Map, Illustrations in Colours, and Wood Engravings. 8vo. 21s.

Kemble. — The Saxons in England: A History of the English Commonwealth till the Conquest. By J. M. KEMBLE, M.A. 2 vols. 8vo. 28s.

Keith Johnston's Dictionary of Geography, Descriptive, Physical, Statistical, and Historical: Forming a complete General Gazetteer of the World. *Third Edition,* rectified to May 1859. In 1 vol. of 1,360 pages, comprising about 50,000 Names of Places, 8vo. 30s. cloth; or half-bound in russia, 35s.

Kesteven. — A Manual of the Domestic Practice of Medicine. By W. B. KESTEVEN, F.R.C.S.E., &c. Square post 8vo. 7s. 6d.

Kirby and Spence's Introduction to Entomology; or, Elements of the Natural History of Insects: Comprising an Account of Noxious and Useful Insects, of their Metamorphoses, Food, Stratagems, Habitations, Societies, Motions, Noises, Hybernation, Instinct, &c. *Seventh Edition,* with an Appendix relative to the Origin and Progress of the work. Crown 8vo. 5s.

A Lady's Tour round Monte Rosa; with Visits to the Italian Valleys of Anzasca, Mastalone, Camasco, Sesia, Lys, Challant, Aosta, and Cogne: In a Series of Excursions in the Years 1850, 1856, 1858. With Map, 4 Illustrations in Colours from Sketches by Mr. G. Barnard, and 8 Wood Engravings. Post 8vo. 14s.

Lardner's Cabinet Cyclopædia of History, Biography, Literature, the Arts and Sciences, Natural History, and Manufactures. A Series of Original Works by EMINENT WRITERS. Complete in 132 vols. fcp. 8vo. with Vignette Titles, price £19. 19s. cloth lettered.

The Works *separately,* in single Volumes or Sets, price 3s. 6d. each Volume, cloth lettered.

Mrs. R. Lee's Elements of Natural History; or, First Principles of Zoology: Comprising the Principles of Classification, interspersed with amusing and instructive Accounts of the most remarkable Animals. New Edition; Woodcuts. Fcp. 8vo. 7s. 6d.

The Letters of a Betrothed. Fcp. 8vo. price 5s. cloth.

Letters to my Unknown Friends. By a LADY, Author of *Letters on Happiness. Fourth Edition.* Fcp. 8vo. 5s.

L.E.L. — The Poetical Works of Letitia Elizabeth Landon; comprising the *Improvisatrice*, the *Venetian Bracelet*, the *Golden Violet*, the *Troubadour*, and Poetical Remains. 2 vols. 16mo. 10s. cloth; morocco, 21s.

Dr. John Lindley's Theory and Practice of Horticulture; or, an Attempt to explain the principal Operations of Gardening upon Physiological Grounds: Being the Second Edition of the *Theory of Horticulture*, much enlarged; with 98 Woodcuts. 8vo. 21s.

Dr. John Lindley's Introduction to Botany. New Edition, with corrections and copious Additions. 2 vols. 8vo. with Plates and Woodcuts, 24s.

Dr. John Lindley's Synopsis of the British Flora arranged according to the Natural Orders; containing Vasculares or Flowering Plants. *Third Edition* (reprinted). Fcp. 8vo. 6s.

Linwood. — Anthologia Oxoniensis, sive Florilegium e Lusibus poeticis diversorum Oxoniensium Græcis et Latinis decerptum. Curante GULIELMO LINWOOD, M.A. 8vo. 14s.

Lorimer's Letters to a Young Master Mariner on some Subjects connected with his Calling. Fcp. 8vo. price 5s. 6d.

Loudon's Encyclopædia of Gardening: Comprising the Theory and Practice of Horticulture, Floriculture, Aboriculture, and Landscape-Gardening. With 1,000 Woodcuts. 8vo. 31s. 6d.

Loudon's Encyclopædia of Trees and Shrubs, or *Arboretum et Fruticetum Britannicum* abridged: Containing the Hardy Trees and Shrubs of Great Britain, Native and Foreign, Scientifically and Popularly Described. With about 2,000 Woodcuts. 8vo. 50s.

Loudon's Encyclopædia of Agriculture: Comprising the Theory and Practice of the Valuation, Transfer, Laying-out, Improvement, and Management of Landed Property, and of the Cultivation and Economy of the Animal and Vegetable Productions of Agriculture. With 1,100 Woodcuts. 8vo. 31s. 6d.

Loudon's Encyclopædia of Plants: Comprising the Specific Character, Description, Culture, History, Application in the Arts, and every other desirable Particular respecting all the Plants found in Great Britain. With upwards of 12,000 Woodcuts. 8vo. price £3. 13s. 6d.

Loudon's Encyclopædia of Cottage, Farm, and Villa Architecture and Furniture. New Edition, edited by Mrs. LOUDON; with more than 2,000 Woodcuts. 8vo. 63s.

Loudon's Hortus Britannicus; or, Catalogue of all the Plants found in Great Britain. New Edition, corrected by Mrs. LOUDON. 8vo. 31s. 6d.

Mrs. Loudon's Lady's Country Companion; or, How to Enjoy a Country Life Rationally. Fourth Edition. Fcp. 8vo. 5s.

Mrs. Loudon's Amateur Gardener's Calendar, or Monthly Guide to what should be avoided and done in a Garden. Second Edition, revised. Crown 8vo. with Woodcuts, 7s. 6d.

Low's Elements of Practical Agriculture; comprehending the Cultivation of Plants, the Husbandry of the Domestic Animals, and the Economy of the Farm. New Edition; with 200 Woodcuts. 8vo. 21s.

Macaulay. — Speeches of the Right Hon. Lord MACAULAY. Corrected by HIMSELF. 8vo. 12s.

Macaulay. — The History of England from the Accession of James II. By the Right Hon. Lord MACAULAY. New Edition. Vols. I. and II. 8vo. 32s.; Vols. III. and IV. 36s.

Lord Macaulay's History of England from the Accession of James II. New Edition of the first Four Volumes of the Octavo Edition, revised and corrected. 7 vols. post 8vo. 6s. each.

Lord Macaulay's Critical and Historical Essays contributed to The Edinburgh Review. Four Editions:—

1. A LIBRARY EDITION (the *Eighth*), in 3 vols. 8vo. price 36s.
2. Complete in ONE VOLUME, with Portrait and Vignette. Square crown 8vo. price 21s. cloth; or 30s. calf.
3. Another NEW EDITION, in 3 vols. fcp. 8vo. price 21s. cloth.
4. The PEOPLE'S EDITION, in 2 vols. crown 8vo. price 8s. cloth.

Macaulay. — Lays of Ancient Rome, with *Ivry* and the *Armada.* By the Right Hon. Lord MACAULAY. New Edition. 16mo. price 4s. 6d. cloth; or 10s. 6d. bound in morocco.

Lord Macaulay's Lays of Ancient Rome. With numerous Illustrations, Original and from the Antique, drawn on Wood by George Scharf, jun. Fcp. 4to. 21s. boards; or 42s. bound in morocco.

Mac Donald.—Poems. By George MAC DONALD, Author of ***Within and Without.*** Fcp. 8vo. 7s.

Mac Donald. — Within and Without: A Dramatic Poem. By GEORGE MAC DONALD. Fcp. 8vo. 4s. 6d.

Mac Dougall. — The Theory of War illustrated by numerous Examples from History. By Lieutenant-Colonel MAC DOUGALL, Commandant of the Staff College. *Second Edition*, revised. Post 8vo. with Plans, 10s. 6d.

Mac Dougall. — The Campaigns of Hannibal, arranged and critically considered, expressly for the use of Students of Military History. By Lieut.-Col. P. L. MAC DOUGALL, Commandant of the Staff College. Post 8vo. 7s. 6d.

M'Dougall. — The Eventful Voyage of *H.M. Discovery Ship* Resolute *to the Arctic Regions in search of Sir John Franklin and the Missing Crews of H.M. Discovery Ships* Erebus *and* Terror, 1852, 1853, 1854. By GEORGE F. M'DOUGALL, Master. With a coloured Chart, Illustrations in Lithography, and Woodcuts. 8vo. 21s.

Sir James Mackintosh's Miscellaneous Works: Including his Contributions to The Edinburgh Review. Complete in One Volume; with Portrait and Vignette. Square crown 8vo. 21s. cloth; or 30s. bound in calf: or in 3 vols. fcp. 8vo. 21s.

Sir James Mackintosh's History of England from the Earliest Times to the final Establishment of the Reformation. 2 vols. 8vo. 21s.

M'Culloch's Dictionary, Practical, Theoretical, and Historical, of Commerce, and Commercial Navigation. Illustrated with Maps and Plans. New Edition, revised and adapted to the Present Time.
[*Just ready.*

M'Culloch's Dictionary, Geographical, Statistical, and Historical, of the various Countries, Places, and principal Natural Objects in the World. Illustrated with Six large Maps. New Edition, revised. 2 vols. 8vo. 63s.

Maguire. — Rome; its Ruler and its Institutions. By JOHN FRANCIS MAGUIRE, M.P. *Second Edition*, enlarged; with a new Portrait of Pope Pius IX. Post 8vo. 10s. 6d.

Mrs. Marcet's Conversations on Natural Philosophy, in which the Elements of that Science are familiarly explained. Thirteenth Edition, enlarged and corrected; with 34 Plates. Fcp. 8vo. price 10s. 6d.

Mrs. Marcet's Conversations on Chemistry, in which the Elements of that Science are familiarly explained and illustrated by Experiments. New Edition, improved. 2 vols. fcp. 8vo. 14s.

Marshman.—The Life and Times of Carey, Marshman, and Ward: Embracing the History of the Serampore Mission. By JOHN CLARK MARSHMAN. 2 vols. 8vo. 25s.

Martineau. — Studies of Christianity: A Series of Original Papers, now first collected, or New. By JAMES MARTINEAU. Crown 8vo. 7s. 6d.

Martineau. — Endeavours after the Christian Life: Discourses. By JAMES MARTINEAU. 2 vols. post 8vo. price 7s. 6d. each.

Martineau. — Hymns for the Christian Church and Home. Collected and edited by JAMES MARTINEAU. *Eleventh Edition*, 12mo. 3s. 6d. cloth, or 5s. calf; *Fifth Edition*, 32mo. 1s. 4d. cloth, or 1s. 8d. roan.

Martineau.—Miscellanies: Comprising Essays chiefly religious and controversial. By JAMES MARTINEAU. Crown 8vo. 9s.

Maunder's Scientific and Literary Treasury: A new and popular Encyclopædia of Science and the Belles-Lettres; including all Branches of Science, and every subject connected with Literature and Art. Fcp. 8vo. 10s.

Maunder's Biographical Treasury; consisting of Memoirs, Sketches, and brief Notices of above 12,000 Eminent Persons of All Ages and Nations, from the Earliest Period of History: Forming a complete Dictionary of Universal Biography. *Eleventh Edition*, corrected and extended in a Supplement to the Present Time. Fcp. 8vo. 10s.

Maunder's Treasury of Knowledge, and Library of Reference; comprising an English Dictionary and Grammar, a Universal Gazetteer, a Classical Dictionary, a Chronology, a Law Dictionary, a Synopsis of the Peerage, numerous useful Tables, &c. New Edition, reconstructed by B. B. WOODWARD, B.A.; assisted by J. MORRIS, Solicitor, and W. HUGHES, F.R.G.S. Fcp. 8vo. 10s.

Maunder's Treasury of Natural History; or, a Popular Dictionary of Animated Nature: In which the Zoological Characteristics that distinguish the different Classes, Genera, and Species, are combined with a variety of interesting Information illustrative of the Habits, Instincts, and General Economy of the Animal Kingdom. With 900 Woodcuts. Fcp. 10s.

Maunder's Historical Treasury; comprising a General Introductory Outline of Universal History, Ancient and Modern, and a Series of Separate Histories of every principal Nation that exists; their Rise, Progress, and Present Condition, the Moral and Social Character of their respective Inhabitants, their Religion, Manners, and Customs, &c. Fcp. 8vo. 10s.

Maunder's Treasury of Geography, Physical, Historical, Descriptive, and Political; containing a succinct Account of Every Country in the World: Preceded by an Introductory Outline of the History of Geography; a Familiar Inquiry into the Varieties of Race and Language exhibited by different Nations; and a View of the Relations of Geography to Astronomy and the Physical Sciences. Completed by WILLIAM HUGHES, F.R.G.S. With 7 Maps and 16 Steel Plates. Fcp. 8vo. 10s.

Merivale (Miss). — Christian Records: A Short History of Apostolic Age. By L. A. MERIVALE. Fcp. 8vo. price 7s. 6d.

Merivale. — The Fall of the Roman Republic: A Short History of Last Century of the Commonwealth. By Rev. C. MERIVALE. 12mo. 7s. 6d.

Merivale. — A History of the Romans under the Empire. By the Rev. CHARLES MERIVALE, B.D., late Fellow of St. John's College, Cambridge. 8vo. with Maps.

VOLS. I and II. comprising the History to the Fall of *Julius Cæsar*. Second Edition, 28s.

VOL. III. to the Establishment of the Monarchy by *Augustus*. Second Edition......14s.

VOLS. IV. and V. from *Augustus* to *Claudius*, B.C. 27 to A.D. 54 ....32s.

VOL. VI. from the Reign of Nero, A.D. 54, to the Fall of Jerusalem, A.D. 70..............16s.

Mildred Norman the Nazarene. By a WORKING MAN. Crown 8vo. 5s.

Miles.—The Horse's Foot and How to Keep it Sound. *Eighth Edition*; with an Appendix on Shoeing in general, and Hunters in particular. 12 Plates and 12 Woodcuts. By W. MILES, Esq. Imperial 8vo. 12s. 6d.

Miles's Plain Treatise on Horse-Shoeing. With Plates and Woodcuts. Second Edition. Post 8vo. 2s.

Milner's History of the Church of Christ. With Additions by the late Rev. ISAAC MILNER, D.D., F.R.S. A New Edition, revised, with additional Notes by the Rev. T. GRANTHAM, B.D. 4 vols. 8vo. 52s.

Minturn. — From New York to Delhi by way of Rio de Janeiro, Australia, and China. By ROBERT B. MINTURN, Jun. With coloured Route-Map of India. Post 8vo. 7s. 6d.

Mollhausen.—Diary of a Journey from the Mississippi to the Coasts of the Pacific, with a United States Government Expedition. By B. MÖLLHAUSEN, Topographical Draughtsman and Naturalist to the Expedition. With an Introduction by Baron HUMBOLDT; Map, coloured Illustrations, and Woodcuts. 2 vols. 8vo. 30s.

James Montgomery's Poetical Works: Collective Edition; with the Author's Autobiographical Prefaces, complete in One Volume; with Portrait and Vignette. Square crown 8vo. 10s. 6d. cloth; morocco, 21s.—Or, in 4 vols. fcp. 8vo. with Plates, 14s.

Moore.—The Power of the Soul over the Body, considered in relation to Health and Morals. By GEORGE MOORE, M.D. Fcp. 8vo. 6s.

Moore.—Man and his Motives. By GEORGE MOORE, M.D. Fcp. 8vo. 6s.

Moore.—The Use of the Body in relation to the Mind. By G. MOORE, M.D. Fcp. 8vo. 6s.

Moore.—Memoirs, Journal, and Correspondence of Thomas Moore. Edited by the Right Hon. LORD JOHN RUSSELL, M.P. With Portraits and Vignettes. 8 vols. post 8vo. £4. 4s.

Thomas Moore's Poetical Works: Comprising the Author's Autobiographical Prefaces, latest Corrections, and Notes. Various Editions of the separate Poems and complete Poetical Works, as follows:—

	s.	d.
LALLA ROOKH, 32mo. ruby type	1	0
LALLA ROOKH, 16mo. Vignette	2	6
LALLA ROOKH, square crown 8vo. Plates	15	0
LALLA ROOKH, fcp. 4to. with Woodcut Illustrations by TENNIEL, in the press.		
IRISH MELODIES, 32mo. ruby type..	1	0
IRISH MELODIES, 16mo. Vignette ..	2	6
IRISH MELODIES, square crown 8vo. Plates	21	0
IRISH MELODIES, illustrated by MACLISE, super-royal 8vo.....	31	6
SONGS, BALLADS, and SACRED SONGS, 32mo. ruby type	2	6
SONGS, BALLADS, and SACRED SONGS, 16mo. Vignette	5	0
POETICAL WORKS, People's Edition, 10 PARTS, each.....	1	0
POETICAL WORKS, Cabinet Edition, 10 VOLS. each.....	3	6
POETICAL WORKS, Traveller's Edition, crown 8vo.....	12	6
POETICAL WORKS, Library Edition, medium 8vo.	21	0
SELECTIONS, entitled "POETRY and PICTURES from THOMAS MOORE," fcp. 4to. with Wood Engravings	21	0
MOORE'S EPICUREAN, 16mo. Vignette.....	5	0

Editions printed with the Music.

	s.	d.
IRISH MELODIES, People's Edition, small 4to.	12	0
IRISH MELODIES, imperial 8vo. small music size	31	6
HARMONISED AIRS from IRISH MELODIES, imperial 8vo.	15	0
NATIONAL AIRS, People's Edition, 10 Nos. each	1	0
NATIONAL AIRS, imperial 8vo. small music size	31	6
SACRED SONGS and SONGS from SCRIPTURE, imperial 8vo.	16	0

No Edition of Thomas Moore's Poetical Works, or any separate Poem of Moore's, can be published complete except by Messrs. LONGMAN and Co.

Morell.—Elements of Psychology: PART I., containing the Analysis of the Intellectual Powers. By J. D. MORELL, M.A., One of Her Majesty's Inspectors of Schools. Post 8vo. 7s. 6d.

Morning Clouds. By the Author of *The Afternoon of Life.* Second Edition, revised throughout. Fcp. 8vo. 5s.

Morris (F. O.)—Anecdotes in Natural History. By the Rev. F. O. MORRIS, B.A., Rector of Nunburnholme, Yorkshire, Author of "History of the Nests and Eggs of British Birds," &c. Fcp. 8vo. [*Just ready.*

Morris (J.)—The Life and Martyrdom of St. Thomas Becket, Archbishop of Canterbury and Legate of the Holy See. By JOHN MORRIS, Canon of Northampton. Post 8vo. 9s.

Morton.—The Resources of Estates: A Treatise on the Agricultural Improvement and General Management of Landed Property. By JOHN LOCKHART MORTON, Civil and Agricultural Engineer; Author of Thirteen Highland and Agricultural Prize Essays. With 25 Lithographic Illustrations. Royal 8vo. 31s. 6d.

Moseley's Mechanical Principles of Engineering and Architecture. Second Edition, enlarged; with numerous Woodcuts. 8vo. 24s.

Memoirs and Letters of the late Colonel ARMINE MOUNTAIN, Aide-de-Camp to the Queen, and Adjutant-General of Her Majesty's Forces in India. Edited by Mrs. MOUNTAIN. Second Edition, Portrait. Fcp. 8vo. 6s.

Mure.—A Critical History of the Language and Literature of Ancient Greece. By WILLIAM MURE, of Caldwell. VOLS. I. to III. 8vo. price 36s.; VOL. IV. 15s.; and VOL. V. 18s.

Murray's Encyclopædia of Geography, comprising a complete Description of the Earth: Exhibiting its Relation to the Heavenly Bodies, its Physical Structure, the Natural History of each Country, and the Industry, Commerce, Political Institutions, and Civil, and Social State of All Nations. Second Edition; with 82 Maps, and upwards of 1,000 other Woodcuts. 8vo. 60s.

Neale.—The Closing Scene; or, Christianity and Infidelity contrasted in the Last Hours of Remarkable Persons. By the Rev. ERSKINE NEALE, M.A. 2 vols. fcp. 8vo. 6s. each.

Normanby (Marquis of).—A Year of Revolution. From a Journal kept in Paris in the Year 1848. By the Marquis of Normanby, K.G. 2 vols. 8vo. 24s.

Ogilvie.—The Master-Builder's Plan; or, the Principles of Organic Architecture as indicated in the Typical Forms of Animals. By George Ogilvie, M.D. Post 8vo. with 72 Woodcuts, price 6s. 6d.

Oldacre.—The Last of the Old Squires. A Sketch. By Cedric Oldacre, Esq., of Sax-Normanbury. Crown 8vo. 9s. 6d.

Osborn.—Quedah; or, Stray Leaves from a Journal in Malayan Waters. By Captain Sherard Osborn, R.N., C.B. With a coloured Chart and tinted Illustrations. Post 8vo. 10s. 6d.

Osborn.—The Discovery of the North-West Passage by H.M.S. *Investigator*, Captain R. M'Clure, 1850-1854. Edited by Captain Sherard Osborn, C.B. Third Edition; with Portrait, Chart, and Illustrations. 8vo. 15s.

Professor Owen's Lectures on the Comparative Anatomy and Physiology of the Invertebrate Animals, delivered at the Royal College of Surgeons. Second Edition, with 235 Woodcuts. 8vo. 21s.

Professor Owen's Lectures on the Comparative Anatomy and Physiology of the Vertebrate Animals, delivered at the Royal College of Surgeons in 1844 and 1846. Vol. I. 8vo. 14s.

Memoirs of Admiral Parry, the Arctic Navigator. By his Son, the Rev. E. Parry, M.A., Domestic Chaplain to the Bishop of London. Sixth Edition; with a Portrait and coloured Chart of the North-West Passage. Fcp. 8vo. 5s.

Pattison.—The Earth and the Word; or, Geology for Bible Students. By S. R. Pattison, F.G.S. Fcp. 8vo. with coloured Map, 3s. 6d.

Peaks, Passes, and Glaciers: a Series of Excursions by Members of the Alpine Club. Edited by John Ball, M.R.I.A., F.L.S., President of the Alpine Club. *Second Edition;* with numerous Maps, coloured Illustrations, and Engravings on Wood. Square crown 8vo. 21s.—The Eight Swiss Maps, accompanied by a Table of the Heights of Mountains, may be had separately, price 3s. 6d.

Dr. Pereira's Elements of Materia Medica and Therapeutics. *Third Edition*, enlarged and improved from the Author's Materials by A. S. Taylor, M.D., and G. O. Rees, M.D. Vol. I. 8vo. 28s.; Vol. II. Part I. 21s.; Vol. II. Part II. 26s.

Dr. Pereira's Lectures on Polarised Light, together with a Lecture on the Microscope. 2d Edition, enlarged from the Author's Materials by Rev. B. Powell, M.A. Fcp. 8vo. Woodcuts, price 7s.

Perry.—The Franks, from their First Appearance in History to the Death of King Pepin. By Walter C. Perry, Barrister-at-Law. 8vo. 12s. 6d.

Peschel's Elements of Physics. Translated from the German, with Notes, by E. West. With Diagrams and Woodcuts. 3 vols. fcp. 8vo. 21s.

Phillips's Elementary Introduction to Mineralogy. A New Edition, with extensive Alterations and Additions, by H. J. Brooke, F.R.S., F.G.S.; and W. H. Miller, M.A., F.G.S. With numerous Woodcuts. Post 8vo. 18s.

Phillips.—A Guide to Geology. By John Phillips, M.A., F.R.S., F.G.S., &c. Fourth Edition, corrected; with 4 Plates. Fcp. 8vo. 5s.

Piesse's Chymical, Natural, and Physical Magic, for the Instruction and Entertainment of Juveniles during the Holiday Vacation: with 30 Woodcuts and an Invisible Portrait of the Author. Fcp. 8vo. 3s. 6d.

Piesse's Art of Perfumery, and Methods of Obtaining the Odours of Plants; with Instructions for the Manufacture of Perfumes for the Handkerchief, Scented Powders, Odorous Vinegars, Dentifrices, Pomatums, Cosmétiques, Perfumed Soap, &c.; and an Appendix on the Colours of Flowers, Artificial Fruit Essences, &c. *Second Edition;* Woodcuts. Crown 8vo. 8s. 6d.

Pitt.—How to Brew Good Beer: A complete Guide to the Art of Brewing Ale, Bitter Ale, Table Ale, Brown Stout, Porter, and Table Beer. To which are added Practical Instructions for Making Malt. By John Pitt, Butler to Sir William R. P. Geary, Bart. Fcp. 8vo. 4s. 6d.

Porter.—History of the Knights of Malta, or the Order of the Hospital of St. John of Jerusalem. By Major Whitworth Porter, Royal Engineers. With 5 Illustrations. 2 vols. 8vo. 24s.

Powell.—Essays on the Spirit of the Inductive Philosophy, the Unity of Worlds, and the Philosophy of Creation. By the Rev. Baden Powell, M.A., &c. Crown 8vo. Woodcuts, 12s. 6d.

Powell. — Christianity without Judaism: A Second Series of Essays on the Unity of Worlds and of Nature. By the Rev. Baden Powell, M.A., &c. Crown 8vo. 7s. 6d.

"This volume contains the pith of Professor Powell's argument urged often and powerfully against the Judaic spirit among Christians. ....Upon the theological part of Professor Powell's argument we offer no opinion; we simply desire to make known the nature of his book, and to secure for it the respect and attention it deserves." Examiner.

Powell.—The Order of Nature considered in reference to the Claims of Revelation: A Third Series of Essays on the Unity of Worlds and of Nature. By the Rev. Baden Powell, M.A. Crown 8vo. 12s.

Pycroft.—The Collegian's Guide; or, Recollections of College Days: Setting forth the Advantages and Temptations of a University Education. By the Rev. J. Pycroft, B.A. *Second Edition.* Fcp. 8vo. 6s.

Pycroft's Course of English Reading; or, How and What to Read: Adapted to every taste and capacity. With Literary Anecdotes. Fcp. 8vo. 5s.

Pycroft's Cricket-Field; or, the Science and History of the Game of Cricket. Third Edition; Plates and Woodcuts. Fcp. 8vo. 5s.

Quatrefages (A. De).—Rambles of a Naturalist on the Coasts of France, Spain, and Sicily. By A. De Quatrefages, Memb. Inst. Translated by E. C. Otté. 2 vols. post 8vo. 15s.

Raikes (T.)—Portion of the Journal kept by Thomas Raikes, Esq., from 1831 to 1847: Comprising Reminiscences of Social and Political Life in London and Paris during that period. New Edition, complete in 2 vols. crown 8vo. price 12s.

Rich's Illustrated Companion to the Latin Dictionary and Greek Lexicon; Forming a Glossary of all the Words representing Visible Objects connected with the Arts, Manufactures, and Every-Day Life of the Ancients. With about 2,000 Woodcuts from the Antique. Post 8vo. 21s.

Richardson.—Fourteen Years' Experience of Cold Water: Its Uses and Abuses. By Captain M. Richardson. Post 8vo. Woodcuts, 6s.

Horsemanship; or, the Art of Riding and Managing a Horse, adapted to the Guidance of Ladies and Gentlemen on the Road and in the Field: With Instructions for Breaking-in Colts and Young Horses. By Captain Richardson, late of the 4th Light Dragoons. With 5 Plates. Square crown 8vo. 14s.

Riddle's Complete Latin-English and English-Latin Dictionary, for the use of Colleges and Schools. *New Edition,* revised and corrected. 8vo. 21s.

Riddle's Diamond Latin-English Dictionary. A Guide to the Meaning, Quality, and right Accentuation of Latin Classical Words. Royal 32mo. 4s.

Riddle's Copious and Critical Latin-English Lexicon, founded on the German-Latin Dictionaries of Dr. William Freund. Post 4to. 31s. 6d.

Rivers's Rose-Amateur's Guide; containing ample Descriptions of all the fine leading variety of Roses, regularly classed in their respective Families; their History and Mode of Culture. Sixth Edition. Fcp. 8vo. 3s. 6d.

Dr. E. Robinson's Greek and English Lexicon to the Greek Testament. A New Edition, revised and in great part re-written. 8vo. 18s.

Mr. Henry Rogers's Essays selected from Contributions to the *Edinburgh Review.* Second Edition, with Additions. 3 vols. fcp. 8vo. 21s.

Samuel Rogers's Recollections of Personal and Conversational Intercourse with Charles James Fox, Edmund Burke, Henry Grattan, Richard Porson, John Horne Tooke, Prince Talleyrand, Lord Erskine, Sir Walter Scott, Lord Grenville, *and* the Duke of Wellington. *Second Edition.* Fcp. 8vo. 5s.

Dr. Roget's Thesaurus of English Words and Phrases classified and arranged so as to facilitate the Expression of Ideas and assist in Literary Composition. Eighth Edition, revised and improved. Crown 8vo. 10s. 6d.

Ronalds's Fly-Fisher's Entomology: With coloured Representation of the Natural and Artificial Insects, and a few Observations and Instructions on Trout and Grayling Fishing. *Fifth Edition*; with 20 new-coloured Plates. 8vo. 14s.

Rowton's Debater: A Series of complete Debates, Outlines of Debates, and Questions for Discussion; with ample References to the best Sources of Information. Fcp. 8vo. 6s.

Dr. C. W. Russell's Life of Cardinal Mezzofanti: With an Introductory Memoir of eminent Linguists, Ancient and Modern. With Portrait and Facsimiles. 8vo. 12s.

Scherzer.—Travels in the Free States of Central America: Nicaragua, Honduras, and San Salvador. By Dr. Carl Scherzer. 2 vols. post 8vo. 16s.

SchimmelPenninck (Mrs.)— Life of Mary Anne SchimmelPenninck. Edited by her relation, Christiana C. Hankin. Third Edition, with Portrait. Post 8vo. 10s. 6d.

SchimmelPenninck's (Mrs.) Select Memoirs of Port Royal. *Fifth Edition*, revised, &c. by the Author's relation, Christiana C. Hankin. 3 vols. post 8vo. 21s.

SchimmelPenninck's (Mrs.) Principles of Beauty; with an Essay on the Temperaments, and Thoughts on Grecian and Gothic Architecture. Edited by the Author's relation, C. C. Hankin. Post 8vo. with coloured Illustrations, price 12s. 6d.

Dr. L. Schmitz's History of Greece, mainly based upon Bishop Thirlwall's History. *Fifth Edition*, with Nine new Supplementary Chapters on the Civilisation, Religion, Literature, and Arts of the Ancient Greeks, contributed by C. H. Watson, M.A. Trin. Coll. Camb.; also a Map of Athens and 137 Woodcuts designed by G. Scharf, jun., F.S.A. 12mo. 7s. 6d.

Scoffern (Dr.)—Projectile Weapons of War and Explosive Compounds. By J. Scoffern, M.B. Lond., late Professor of Chemistry in the Aldersgate College of Medicine. *Fourth Edition*. Post 8vo. Woodcuts, 9s. 6d.

Senior.—Journal kept in Turkey and Greece in the Autumn of 1857 and the beginning of 1858. By Nassau W. Senior, Esq. With 2 Maps and 2 Views. Post 8vo. 12s.

Sewell (Miss).—New Edition of the Tales and Stories of the Author of *Amy Herbert*, in 9 vols. crown 8vo. price £1. 10s. cloth; or each work complete in one volume, separately as follows:—

AMY HERBERT	2s. 6d.
GERTRUDE	2s. 6d.
The EARL'S DAUGHTER	2s. 6d.
The EXPERIENCE of LIFE	2s. 6d.
CLEVE HALL	3s. 6d.
IVORS, or the Two Cousins	3s. 6d.
KATHARINE ASHTON	3s. 6d.
MARGARET PERCIVAL	5s. 0d.
LANETON PARSONAGE	4s. 6d.

Also by the Author of Amy Herbert.

Ursula: A Tale of English Country Life. 2 vols. fcp. 8vo. 12s.

History of the Early Church: from the First Preaching of the Gospel to the Council of Nicea. 18mo. 4s. 6d.

Self-Examination before Confirmation: With Devotions and Directions for Confirmation-Day. 32mo. 1s. 6d.

Readings for a Month preparatory to Confirmation: Compiled from the Works of Writers of the Early and of the English Church. Fcp. 8vo. 4s.

Readings for every Day in Lent: Compiled from the Writings of Bishop Jeremy Taylor. Fcp. 8vo. 5s.

Bowdler's Family Shakspeare: In which nothing is *added* to the Original Text; but those words and expressions are *omitted* which cannot with propriety be read aloud. Illustrated with 36 Woodcut Vignettes. The *Library Edition*, in One Volume, medium 8vo. price 21s.; a *Pocket Edition*, in 6 vols. fcp. 8vo. price 5s. each.

Sharp's New British Gazetteer, or Topographical Dictionary of the British Islands and narrow Seas: Comprising concise Descriptions of about 60,000 Places, Seats, Natural Features, and Objects of Note, founded on the best authorities. 2 vols. 8vo. £2. 16s.

Short Whist; its Rise, Progress, and Laws: With Observations to make any one a Whist-Player. Containing also the Laws of Piquet, Cassino, Ecarté, Cribbage, Backgammon. By Major A. New Edition; with Precepts for Tyros, by Mrs. B. Fcp. 8vo. 3s.

Simpson.—Handbook of Dining; or, How to Dine, theoretically, philosophically, and historically considered: Based chiefly upon the *Physiologie du Goût* of Brillat-Savarin. By Leonard Francis Simpson, M.R.S.L. Fcp. 8vo. 5s.

Sinclair. — The Journey of Life. By Catherine Sinclair, Author of *The Business of Life*. Fcp. 8vo. 5s.

Sir Roger De Coverley. From the Spectator. With Notes and Illustrations, by W. Henry Wills; and 12 Wood Engravings from Designs by F. Tayler. Crown 8vo. 10s. 6d.; or 21s. in morocco by Hayday.

The Sketches · Three Tales. By the Authors of *Amy Herbert*, *The Old Man's Home*, and *Hawkstone*. Fcp. 8vo. price 4s. 6d.

Smee's Elements of Electro-Metallurgy. Third Edition, revised; with Electrotypes and numerous Woodcuts. Post 8vo. 10s. 6d.

Smith (G.) — History of Wes-leyan Methodism. By George Smith, F.A.S., Author of *Sacred Annals*, &c. Vol. I. *Wesley and his Times*; Vol. II. *The Middle Age of Methodism*, from 1791 to 1816. Crown 8vo. 10s. 6d. each.

Smith (J.) — The Voyage and Shipwreck of St. Paul: With Dissertations on the Life and Writings of St. Luke, and the Ships and Navigation of the Ancients. By James Smith, F.R.S. With Charts, Views, and Woodcuts. Crown 8vo. 8s. 6d.

A Memoir of the Rev. Sydney Smith. By his Daughter, Lady Holland. With a Selection from his Letters, edited by Mrs. Austin. *New Edition.* 2 vols. 8vo. 28s.

The Rev. Sydney Smith's Mis-cellaneous Works: Including his Contributions to The Edinburgh Review. Four Editions:—

1. A Library Edition (the *Fourth*), in 3 vols. 8vo. with Portrait, 36s.
2. Complete in One Volume, with Portrait and Vignette. Square crown, 8vo. 21s. cloth; or 30s. bound in calf.
3. Another New Edition, in 3 vols. fcp. 8vo. 21s.
4. The People's Edition, in 2 vols. crown 8vo. price 8s. cloth.

The Rev. Sydney Smith's Ele-mentary Sketches of Moral Philosophy, delivered at the Royal Institution in the Years 1804 to 1806. Fcp. 8vo. 7s.

Snow. — Two Years' Cruise off Tierra del Fuego, the Falkland Islands, Patagonia, and in the River Plate: A Narrative of Life in the Southern Seas. By W. Parker Snow, late Commander of the Mission Yacht *Allen Gardiner*. With Charts and Illustrations. 2 vols. post 8vo. 24s.

Robert Southey's Complete Poet-ical Works; containing all the Author's last Introductions and Notes. The *Library Edition*, complete in One Volume, with Portraits and Vignette. Medium 8vo. 21s. cloth; 42s. bound in morocco. — Also, the *First collected Edition*, in 10 vols. fcp. 8vo. with Portrait and 19 Vignettes, price 35s.

Southey's Doctor, complete in One Volume. Edited by the Rev. J. W. Warter, B.D. With Portrait, Vignette, Bust, and coloured Plate. Square crown 8vo. 21s.

Southey's Life of Wesley; and Rise and Progress of Methodism. Fourth Edition, edited by Rev. C. C. Southey, M.A. 2 vols. crown 8vo. 12s.

Spencer.—Essays, Scientific, Po-litical, and Speculative. By Herbert Spencer, Author of *Social Statics*. Reprinted chiefly from Quarterly Reviews. 8vo. 12s. cloth.

Spencer. — The Principles of Psychology. By Herbert Spencer, Author of *Social Statics*. 8vo. 16s.

Stephen. — Lectures on the His-tory of France. By the Right Hon. Sir James Stephen, K.C.B., LL.D. Third Edition. 2 vols. 8vo. 24s.

Stephen. — Essays in Ecclesiastical Biography; from The Edinburgh Review. By the Right Hon. Sir James Stephen, K.C.B., LL.D. Third Edition. 2 vols. 8vo. 24s.

Stonehenge.—The Dog in Health and Disease: Comprising the various Modes of Breaking and using him for Hunting, Coursing, Shooting, &c.; and including the Points or Characteristics of Toy Dogs. By Stonehenge. With about 70 Illustrations engraved on Wood. Square crown 8vo. price 15s. half-bound.

Stonehenge's Work on the Greyhound: Being a Treatise on the Art of Breeding, Rearing, and Training Greyhounds for Public Running; their Diseases and Treatment: Containing also Rules for the Management of Coursing Meetings, and for the Decision of Courses. With Frontispiece and Woodcuts. Square crown 8vo. 21s.

Stow's Training System, Moral Training School, and Normal Seminary for preparing Schoolmasters and Governesses. Eleventh Edition; Plates and Woodcuts. Post 8vo. 6s. 6d.

Strickland.—Lives of the Queens of England. By Agnes Strickland. Dedicated, by express permission, to Her Majesty. Embellished with Portraits of every Queen, engraved from the most authentic sources. Complete in 8 vols. post 8vo. 7s. 6d. each.

Symonds.—Memoirs of the Life and Services of Rear-Admiral Sir William Symonds, late Surveyor of the Navy. Edited by J. A. Sharp. 8vo. with Illustrations, price 21s.

Taylor.—Loyola: and Jesuitism in its Rudiments. By Isaac Taylor. Post 8vo. Medallion, 10s. 6d.

Taylor.—Wesley and Methodism. By Isaac Taylor. Post 8vo. Portrait, 10s. 6d.

Tennent.—Ceylon: An Account of the Island, Physical, Historical, and Topographical: with Copious Notices of its Natural History, Antiquities, and Productions. Illustrated by 7 Maps, 17 Plans and Charts, and 101 Engravings on Wood. By Sir J. Emerson Tennent, K.C.S., LL.D., &c. 2 vols. 8vo. price 50s.

Bishop Thirlwall's History of Greece. Library Edition; with Maps. 8 vols. 8vo. £3.—An Edition in 8 vols. fcp. 8vo. with Vignette Titles, 28s.

Thomson's Seasons. Edited by Bolton Corney, Esq. Illustrated with 77 fine Wood Engravings from Designs by Members of the Etching Club. Square crown 8vo. 21s. cloth; or 36s. bound in morocco.

Thomson (the Rev. Dr.) — An Outline of the necessary Laws of Thought: A Treatise on Pure and Applied Logic. By William Thomson, D.D. New Edition. Fcp. 8vo. 7s. 6d.

Thomson's Tables of Interest, at Three, Four, Four-and-a-Half, and Five per Cent., from One Pound to Ten Thousand, and from 1 to 365 Days, in a regular progression of single Days; with Interest at all the above Rates, from One to Twelve Months, and from One to Ten Years. Also, numerous other Tables of Exchange, Time, and Discounts. The Seventeenth Edition, thoroughly revised and stereotyped. 12mo. 3s. 6d.

The Thumb Bible; or, Verbum Sempiternum. By J. Taylor. Being an Epitome of the Old and New Testaments in English Verse. Reprinted from the Edition of 1693. 64mo. 1s. 6d.

Todd (Dr.)—The Cyclopædia of Anatomy and Physiology. Edited by Robert B. Todd, M.D., F.R.S., &c., Physician to King's College Hospital; late Professor of General and Morbid Anatomy in King's College, London. Now complete in 5 vols. 8vo. pp. 5,350, illustrated with 2,853 Woodcuts, price £6. 6s. cloth.

Tooke.—History of Prices, and of the State of the Circulation, during the Nine Years from 1848 to 1856 inclusive. Forming Vols. V. and VI. of Tooke's *History of Prices*; and comprising a copious Index to the whole work. By Thomas Tooke, F.R.S. and William Newmarch. 2 vols. 8vo. 52s. 6d.

Trevelyan (Sir C.) — Original Papers illustrating the History of the Application of the Roman Alphabet to the Languages of India. Edited by Monier Williams, M.A., late Professor of Sanskrit in the East-India College, Haileybury. 8vo. with Map, price 12s.

The Traveller's Library: A Collection of original Works well adapted for *Travellers* and *Emigrants*, for *School-room Libraries*, the *Libraries of Mechanics' Institutions*, *Young Men's Libraries*, the *Libraries of Ships*, and similar purposes. The separate volumes are suited for *School Prizes*, *Presents to Young People*, and for general instruction and entertainment. The Series comprises fourteen of the most popular of Lord Macaulay's *Essays*, and his *Speeches* on Parliamentary Reform. The department of Travels contains some account of eight of the principal countries of Europe, as well as travels in four districts of Africa, in four of America, and in three of Asia. Madame Pfeiffer's *First Journey round the World* is included; and a general account of the *Australian Colonies*. In Biography and History will be found Lord Macaulay's Biographical Sketches of *Warren Hastings*, *Clive*, *Pitt*, *Walpole*, *Bacon*, and others; besides Memoirs of *Wellington*, *Turenne*, *F. Arago*, &c.; an Essay on the Life and Genius of *Thomas Fuller*, with Selections from his Writings, by Mr. Henry Rogers; and a history of the *Leipsic Campaign*, by Mr. Gleig,—which is the only separate account of this remarkable campaign. Works of Fiction did not come within the plan of the TRAVELLER'S LIBRARY; but the *Confessions of a Working Man*, by Souvestre, which is indeed a fiction founded on fact, has been included, and has been read with unusual interest by many of the working classes, for whose use it is especially recommended. Dumas's story of the *Maitre-d'Armes*, though in form a work of fiction, gives a striking picture of an episode in the history of Russia. Amongst the works on Science and Natural Philosophy, a general view of Creation is embodied in Dr. Kemp's *Natural History of Creation*; and in his *Indications of Instinct* remarkable facts in natural history are collected. Dr. Wilson has contributed a popular account of the *Electric Telegraph*. In the volumes on the *Coal-Fields*, and on the Tin and other Mining Districts of *Cornwall*, is given an account of the mineral wealth of England, the habits and manners of the miners, and the scenery of the surrounding country. It only remains to add, that among the Miscellaneous Works are a Selection of the best Writings of the Rev. Sydney Smith; Lord Carlisle's *Lectures and Addresses*; an account of *Mormonism*, by the Rev. W. J. Conybeare; an exposition of *Railway* management and mismanagement by Mr. Herbert Spencer; an account of the Origin and Practice of *Printing*, by Mr. Stark; and an account of *London*, by Mr. M'Culloch.—To be had, in *complete Sets only*, at £5. 5s. per Set, bound in cloth and lettered.

☞ *The Traveller's Library* may also be had as originally issued in 102 parts, 1s. each, forming 50 vols. 2s. 6d. each; or any separate parts or volumes.

Trollope.—The Warden, a Novel. By ANTHONY TROLLOPE. New and cheaper Edition. Crown 8vo. 3s. 6d.

Trollope's Barchester Towers, a Sequel to *The Warden*. New and cheaper Edition, complete in One Volume. Crown 8vo. 5s.

Sharon Turner's History of the Anglo-Saxons, from the Earliest Period to the Norman Conquest. 3 vols. 36s.

Dr. Turton's Manual of the Land and Fresh-Water Shells of Great Britain: With Figures of each of the kinds. New Edition, with Additions by Dr. J. E. GRAY, F.R.S., &c., Keeper of the Zoological Collection in the British Museum. Crown 8vo. with 12 coloured Plates, price 15s. cloth.

Dr. Ure's Dictionary of Arts, Manufactures, and Mines: Containing a clear Exposition of their Principles and Practice. New Edition, chiefly rewritten and greatly enlarged; with nearly 2,000 Woodcuts. Edited by ROBERT HUNT, F.R.S., F.S.S., Keeper of Mining Records. In course of publication in 14 Parts, price 5s. each, forming 3 vols. 8vo.

Uwins. — Memoir and Correspondence of THOMAS UWINS, R.A., late Keeper of the Royal Galleries and of the National Gallery, &c. Edited by Mrs. UWINS. 2 vols. post 8vo. 18s.

Van der Hoeven's Handbook of Zoology. Translated by the Rev. WILLIAM CLARK, M.D., F.R.S., Professor of Anatomy in the University of Cambridge. 2 vols. 8vo. with 24 Plates of Figures, price 60s. cloth; or separately, VOL. I. *Invertebrata*, 30s., and VOL. II. *Vertebrata*, 30s.

Vehse.—Memoirs of the Court, Aristocracy, and Diplomacy of Austria. By Dr. E. VEHSE. Translated from the German by FRANZ DEMMLER. 2 vols. post 8vo. 21s.

Von Tempsky.—Mitla; or, Incidents and Personal Adventures on a Journey in Mexico, Guatemala, and Salvador in the Years 1853 to 1855. By G. F. VON TEMPSKY. With numerous Illustrations. 8vo. 18s.

Wade. — England's Greatness: Its Rise and Progress in Government, Laws, Religion, and Social Life; Agriculture, Commerce, and Manufactures; Science, Literature and Arts, from the Earliest Period to the Peace of Paris. By JOHN WADE, Author of the *Cabinet Lawyer*, &c. Post 8vo. 10s. 6d.

Wanderings in the Land of Ham. By a Daughter of Japhet. Post 8vo. 8s. 6d.

Waterton.—Essays on Natural History, chiefly Ornithology. By C. Waterton, Esq. With the Autobiography of the Author, and Views of Walton Hall. 2 vols. fcp. 8vo. 5s. each.

Waterton's Essays on Natural History. Third Series; with a Continuation of the Autobiography, and a Portrait of the Author. Fcp. 8vo. 6s.

Watson. — Cybele Britannica; or, British Plants and their Geographical Relations. By Hewett Cottrell Watson. 4 vols. 8vo. 42s. cloth; or each vol. separately, price 10s. 6d.

Webb. — Celestial Objects for Common Telescopes. By the Rev. T. W. Webb, M.A., F.R.A.S., Incumbent of Hardwick, Herefordshire. With Woodcuts, and Map of the Moon 12 inches in diameter engraved on Steel, 16mo. 7s.

Webster and Parkes's Encyclopædia of Domestic Economy; comprising such subjects as are most immediately connected with Housekeeping: viz. The Construction of Domestic Edifices, with the Modes of Warming, Ventilating, and Lighting them—A description of the various Articles of Furniture, with the Nature of their Materials — Duties of Servants — &c. With nearly 1,000 Woodcuts. 8vo. 50s.

Weld. — The Pyrenees, West and East. By Charles Richard Weld, Barrister-at-Law. With 8 Illustrations in Chromo-xylography from Drawings by the Author. Post 8vo. 12s. 6d.

Weld's Vacation Tour in the United States and Canada. 10s. 6d.

Weld's Vacations in Ireland. Post 8vo. 10s. 6d.

Willich's Popular Tables for ascertaining the Value of Lifehold, Leasehold, and Church Property, Renewal Fines, &c. With numerous additional Tables—Chemical, Astronomical, Trigonometrical, Common and Hyperbolic Logarithms; Constants, Squares, Cubes, Roots, Reciprocals, &c. Fourth Edition. Post 8vo. 10s.

Wilmot's Abridgment of Blackstone's Commentaries on the Laws of England, in a series of Letters from a Father to his Daughter. 12mo. 6s. 6d.

Wilson's Bryologia Britannica: Containing the Mosses of Great Britain and Ireland systematically arranged and described according to the Method of *Bruch* and *Schimper;* with 61 illustrative Plates. Being a New Edition, enlarged and altered, of the *Muscologia Britannica* of Messrs. Hooker and Taylor. 8vo. 42s.; or, with the Plates coloured, price £4. 4s.

Yonge.—A New English-Greek Lexicon: Containing all the Greek Words used by Writers of good authority. By C. D. Yonge, B.A. *Second Edition*, revised. Post 4to. 21s.

Yonge's New Latin Gradus: Containing Every Word used by the Poets of good authority. For the use of Eton, Westminster, Winchester, Harrow, and Rugby Schools; King's College, London; and Marlborough College. *Sixth Edition.* Post 8vo. 9s.; or, with Appendix of *Epithets*, 12s.

Youatt's Work on the Horse: With a Treatise on Draught. New Edition, revised and enlarged by E. N. Gabriel, M.R.C.S., C.V.S., Secretary to the Royal College of Veterinary Surgeons. With numerous Woodcut Illustrations, chiefly from designs by W. Harvey. 8vo. price 10s. 6d. cloth.

Youatt.—The Dog. By William Youatt. A New Edition; with numerous Engravings, from Designs by W. Harvey. 8vo. 6s.

Young.—The Christ of History: An Argument grounded in the Facts of His Life on Earth. By John Young, LL.D. Second Edition. Post 8vo. 7s. 6d.

Young.—The Mystery; or, Evil and God. By John Young, LL.D. Post 8vo. 7s. 6d.

Zumpt's Grammar of the Latin Language. Translated and adapted for the use of English Students by Dr. L. Schmitz, F.R.S.E.: With numerous Additions and Corrections by the Author and Translator. 8vo. 14s.

[*September* 1859.

LONDON : PRINTED BY SPOTTISWOODE & CO. NEW-STREET SQUARE.

WORKS FOR SCHOOLS AND YOUNG PERSONS

[illegible]

BOUND BY WESTLEYS & CO LONDON